ASSESSMENT OF RESERVOIR OPERATION UNDER PARAMETERIC UNCERTAINITY- THE CASE OF GIBE-I RESERVOIR

BY

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DECLARATION

I, Tadewos Adema Amona, declare that this is my own original work and it has not been presented and will not be presented to any other University for similar or any degree award.

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Signature

CERTIFICATION

I,the undersigned, certify that I read and here by recommend for acceptance by Addis Ababa Science and Technology University a dissertation entitled **‘‘ASSESSMENT OF RESERVOIR OPERATION UNDER PARAMETERIC UNCERTAINITY-THE CASE OF GIBE-I RESERVOIR’’** in partial fulfillment of the requirements for the degree of Master of Science in Hydraulic Engineering.

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Dean, College of Architecture and Civil Eng Sign Date

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ABSTRACT

The proper operation of a reservoir under specified demands and hydrologic condition is checked against its Reliability, Resilience and Vulnerability (RRV). This study tried to evaluate the performance of Gibe-I Hydropower Reservoir on the basis of RRV under parametric uncertainty. The input data considered were meteorological and hydrological data for the period 1996 to 2006, dam and reservoir physical and operation data.Hydrologiska Byråns Vattenbalansavdelning (HBV- light)-model in conjunction with Monte Carlo (MC) automatic calibration with in HBV adapted to Generalized Likelihood Uncertainty (GLUE) analysis. Accepted parameter set which was 100 in number used to develop probability distribution of the parametric set. Parametric values at mean and standard deviation were adopted to develop reservoir inflow. Hydrologic Engineering Center Reservoir Simulation Model (HEC-ResSim) was used for analysis of alternative power plant release options and different inflow conditions: Simulated mean flow was used to evaluate two and three units operation. For each alternative, Reliability, Resilience and Vulnerability were computed. When two units are in used at mean inflow, the values of parameters are 96.5%, 93% and 2.4Mm^3 respectively. Similarly, when three units are used, the parameters are 67%, 57% and 3.9Mm^3 respectively. Maximum water levels in the reservoir for two and three units were found to be 1671.4 and 1671.25m.a.s.l respectively. *This indicates that the reservoir is vulnerable to spills of varying magnitudes to inflows and model output was found in good agreement when two units are put in operation. The study concludes that the system is found to be less reliable, spends more time to recover and more vulnerable when used with three units but it shows an improved reliability, with a good recovery time and less vulnerable when used with two units and three units alternatively based real time guide curve operation of Gilgel Gibe-I reservoir..*

Key words*:* Reliability, Resilience, Vurneabilty

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LIST OF ABBREVIATIONS

GLUE	Generalized Likelihood Uncertainty Estimation
HEC-ResSim	Hydrologic Engineering Center Reservoir Simulation Model
MoWR	Ministry of Water Resource
HBV	Hydrologiska Byråns Vattenbalansavdelning Means
MW	Mega Watt
a..s.l	above Sea level
ITCZ	Inter-Tropical Convergence Zone
EIA	Environmental Impact Assessment
HEC-HMS	Hydrologic Engineering Center-Hydrologic modeling and simulation
SMAR	Soil Moisture Accounting and Routing
PET	Potential evapotranspiration
MC	Monte Carlo
MCMC	Markov Chain Monte Carlo
BMCMC	Bayesian Markov Chain Monte Carlo
ARSP	Acres Reservoir Simulation Program
WEAP	Water Evaluation and Planning
GUI	Graphical user interface
HECDSS	HEC Data Storage System
GWH	Giga Watt Hour
MoWIE)	Ministry of Water, irrigation and electricity
NMA	National Meteorology Agency
CMD	Climatologically mean of the day

CHAPTER ONE

1. INTRODUCTION

1.1Background

Optimum operation of reservoir forms an integral part in water resources management that need evaluation under specified demands and hydrologic conditions. This is important to have risk informed decision on making reservoir that aims achieving sustainability through environmental integrity, economic efficiency and equity. Furthermore, a sustainable decision-making regarding water resource faces the challenge of time in which it must identify and account from long-term consequences. An essential aspect in the planning, design and management of sustainable water resources systems is the anticipation of change. This includes change due to the variability in the hydrology, changing in the climate, and change due to geomorphologic processes. Therefore, any sustainable water resources development should incorporate change as essential feature. Although there are many works devoted to changing climate, land use and other anthropogenic impacts on hydropower performance, studies so far been little explored, especially those related to hydrologic model uncertainty. With increasing frequency, hydrologic models have been great operation hydrology i.e. planning and management of water resources system under dynamic environment. Such models are often used in a deterministic fashion that ignores the model uncertainty associated with simulated responses. The impact of ignoring model uncertainty is shown to be magnified for hydrologic events. Recent approaches to hydrological and water resources simulation modeling have emphasized the need to include uncertainty (Pappenberger and Beven ,2006).

Model calibration can be affected by a variety of factors. When the residual between the observed and simulated values reaches its minimum, the model parameter value is considered as the optimum value, which may differ from the true parameter value inferred by the actual physical process (Singh and Bardossy, 2012). Parameters obtained in this manner cannot fully characterize the true state of their corresponding physical process in the real system, thus leading to a great level of uncertainty. Parameter uncertainty will inevitably have an impact on the model simulations, by introducing uncertainties in simulation results (Christiaens and Feven ,2002). How to assess the uncertainties in hydrological model parameters and their impacts on the uncertainty of model simulations has always been a topic of great interest. The quantitative evaluation of parameter uncertainty and its influence on the uncertainty of hydrological model simulations is critical in reducing the uncertainty of these simulations, and in assessing their effectiveness (Hunghes and Sawunyama ,2010).Many methods have been applied to the analysis of parameter uncertainty, of which the Generalized Likelihood Uncertainty Estimation (GLUE) proposed by (K.J & Binley.p, 1992).

Evaluation of reservoirs' operations is usually carried out by using reliability, resilience and vulnerability indices which are considered as the pertinent method to ensure consistent assessment of reservoir system performance (Thomas et al,2004). Among the measures used in planning and management of reservoirs, time and volume reliabilities are frequently employed. Time reliability indicates the proportion of time during an operating horizon for which the reservoir can meet the stipulated demands whereas volume reliability is the volume of water supplied as a fraction of the total target demand during the operating horizon. Nowadays, the exploitation of hydropower potential has been recognized by the Ethiopia as a key issue in the economic development of the country. To meet the strong increase of energy demands in future years, a series of actions for the construction of power plants particularly on the rivers basin. However implementation of the projects needs not only planning and construction but also evaluation of its efficient operation under specified demand and hydrologic condition. Various reservoir planning and management optimization and simulation models have been developed in order to support the decision-making process of the reservoir operation and reviewed by many authors. Often the assessment of system performance can best be addressed with simulation models.

Therefore, in this study the performance of Gilgel Gibe-I reservoir was evaluated under parametric uncertainty using Hydrologiska Byråns Vattenbalansavdelning (HBV-light) model in conjunction with a Hydrologic Engineering Center Reservoir Simulation Model (HEC-ResSim) reservoir simulation model.

1.2 Statement of the problem

Reservoir operation evaluation forms an important part of water resources management and this is the main challenge facing Ethiopian reservoirs and power systems today, and seeks an appropriate solution. This is because, energy production from hydropower is mainly dependent on the availability of water and hence hydrology plays an influential role not only for some specified periods but also throughout the life cycle of the hydropower plants. However, the randomness/uncertainty in the hydrological events would make handling of the hydrological issues more difficult. Moreover, the spatial and temporal variability in hydrology may be significant in the countries which require careful hydrological analyses and forecasting based on stochastic nature of the hydrologic modeling and also for optimal integration of hydropower production scheduling for a country or a region.

In the recent past; Ethiopia has faced with power shortage and hence forced to rationing power several times during dry season, while floods passing reservoirs have been caused considerable damages during wet seasons. This fact mainly stems from lack of efficient hydrological forecasting and water management system for operation of the reservoir in the country. For instance, in 2003, the country suffered its most severe drought in 20 years, reducing reservoir levels across the country, and forcing sudden and severe power rationing in Addis Ababa which lasted for six months, similarly in 2006, an industry journal noted, that Ethiopia's reliance on hydroelectric generating capacity has left the power sector vulnerable to reduced production during the dry season or during the all too regular prolonged droughts (Terri ,2008).

In addition, recently, although there is great tendency of utilizing available water resources, the efficiency of using and managing the resource is limited due to uncertainties in stream flow and inaccurate model outputs that may come due to model efficiencies. (MOWR, 2006).

Gibe- I catchment is one amongst such land resources which are subjected to the land use land cover dynamics which results in disturbance of stream flow regimes of watersheds. This will lead to the condition of land with little vegetative cover and is subject to high surface runoff amounts, low infiltration rate and reduced groundwater recharge. This may cause flooding problems during the wet seasons of the year. The problems mentioned require deep considerations of watershed management activities protecting the basin from the degradation, deforestation and any activity affecting of the basin. In order to effectively utilize the scarce water resources of the development area and to alleviate the adverse effects of the floods arriving at Gibe- I, the reservoir has to be wisely operated.

The wet season floods arriving at the reservoir need to be well managed through implementation of operation rules so as to avoid the possible scarcity of water for the unplanned water needs and ecological purposes during the dry seasons and flooding problems during the wet seasons that will occur as a result of inappropriate storages, spillages and releases. If the forecast indicates water shortages (water of drought) at any time of the year, then supply of the energy must be curtailed in advance to mitigate probable drought loss. The amount to be reduced should be decided by the decision makers based on specific values of rationing. On the other hand, if the forecast indicates water surplus (water of spill) a pre-release strategy for surplus power production should be considered. In doing so, the project operator can minimize the usage of reservoir storage while keeping spillage and deficit to the minimum.

1.3 Significance of the Study

In recent times, there is a significant shift from planning and construction of water resource projects to efficient operation of existing system due to limited water resource and traditional operation and management approaches that need to consider the complexity and uncertainty of the system. Presentation of simultaneous information about these two measures facilitates the interpretation of a water system's performance and comparison of management alternatives. A simulation model is usually characterized as a representation of a physical system used to predict the response of the system under a given set of conditions. At present, most major river systems use optimization to identify the preferred release schedule, and refine this schedule using Simulation. Simulation models may not be able to generate an optimal solution to reservoir problem directly. However, with numerous simulations using alternative decision polices, these models can detect an optimal solution or a near-optimal solution (Simonov, 1992).

Further, the simulation model can be used to study the behavior of the system under derived operating rules and to compute various performance measures of the system operation. Performance measures such as reliability, duration and resiliency, etc. should be considered evaluating the operating rules. Different researches were conducted which is relevant to this topic some of them are, Teshome Seyoum (2015); (Mohammed, 2013),Fikadu. F (2008); Alemaye .H (2012). Even though, evaluation and modification of planning and operation practice of dams and reservoirs might be to the extent possible and encouraged, due to change of hydrologic condition, water characteristics due to the rapid construction of new dams etc., in Ethiopia. This study will endeavor to address this issue. The outcome of the study will provide tangible tools for the possible decision of the operation option and management of the dam and reservoir based on the performance characteristics.

So, this study plays a significant role in such way that it simulates the reservoir system operations using HEC-ResSim for good and optimum performance characterization of operation of the system. The outputs of the study results are generally intended to inform policy makers, water resource managers, and other interested stakeholders to make effective and efficient operation rule development considering optimization and refinement through simulation planning for existing projects and for future.

Therefore, as the very end, the study may bridge the information on performance based planning of reservoir operation rule and sustainable management of water resources viable economically.

1.4 Objective of the Study

1.4.1 General Objective

The main objective of this study to assess the technical performance efficiency by developing historical inflow prediction model under reduced parametric uncertainty for the case of Gibe -I Reservoir.

1.4.2 Specific Objectives

- To investigate and compare the performance indicators of current operating rules of the Gilgel Gibe-I hydropower reservoir.
- To derive and investigate for optimum operation rule that maximize performance of the reservoir
- To recommend on the operation rule of the system based on existing condition

1.5 Structure of the Thesis

The thesis has been organized to have six chapters including the introductory section. General overviews of each chapter are discussed as follows:

CHAPTER ONE:

Comprises the introduction part, problem statement, objectives of the study and significance of the study.

CHAPTER TWO: The literature review about hydrologic modeling and its prediction uncertainty, uncertainty types and uncertainty estimation methods and selected hydrologic model (HBV-light). Also the chapter reviews the selected HEC-ResSim model. Finally, reservoir performance indicators and general condition and previous studies conducted in the basin are broadly discussed in the chapter

CHAPTER THREE:

Description of the study area, including the main characteristics of the Gibe- I river basin including the location, rainfall characteristics, land use and topography. Describes methodology used to achieve the objectives of the thesis. The chapter focuses on hydrological, meteorology, operational and physical data collection and simulation and analysis and performance assessment indicators description.

CHAPTER FOUR:

Hydrologic and Hydropower simulation result and discussion, Reservoir performance indicators result and discussion.

CHAPTER FIVE:

Conclusions and Recommendations from the study

CHAPTER TWO

2. LITERATURE REVIEW

2.1Hydrologic Modeling and Prediction Uncertainty

A proper understanding of the sources and effects of uncertainty is needed to achieve the goals of reliability and sustainability in water resource and management and planning. In the past decade there has been development of techniques for assessing various sources of uncertainty associated with hydrological forecasts (Beven and Binley ,1992).

Despite the development, links between estimated hydrological uncertainties and water resources management uncertainties have not been extensively explored. Investigation of such linkages is especially important since it is not clear how uncertainty in hydrologic modeling might affect the operation rules for reservoir management. Directly impact the outcome of water resources planning and management studies, especially climate change studies that use climate forces (such as precipitation and temperature) to force hydrological models and consequently project the impact of climate change on managing water resources (Chow Ven Te et al. ,1988). Not this study especially accounts for uncertainties associated with the hydrological modeling step, including model parameters and model structural uncertainties. Reliable hydrologic prediction with estimates of associated uncertainties can provide decision makers with information that allows them to incorporate risk in decision making and therefore mitigate some of the social, economic and environmental impact of poor and conservation rules. Hydrologic models are simple mathematical conceptualizations of complex and spatially distributed watershed processes that can be used to provide estimates of current and future hydrologic events. The reliability of these models depends on proper parameter and state estimation; however, errors inherent in meteorological and hydrological observations, model states, model parameters, and model structure ultimately introduce bias and uncertainty into the application.

When models are applied for hydrologic prediction to be used as reservoir inputs, incomplete accounting of these uncertainties may lead to unreliable and inefficient management of our water resources. The most important hydrologic cycle in which hydrologic models base ones, with respect to rainfall-runoff transformation, are described here.This will lead to a better understanding of the rainfall-runoff processes conceptualized by the (HBV-Light) model. The catchment hydrologic cycle involves many processes. Many hydrologists investigated this cycle. A summary of the cycle is given by Chow eta. (1988) and brief description illustrated in figure 2.1

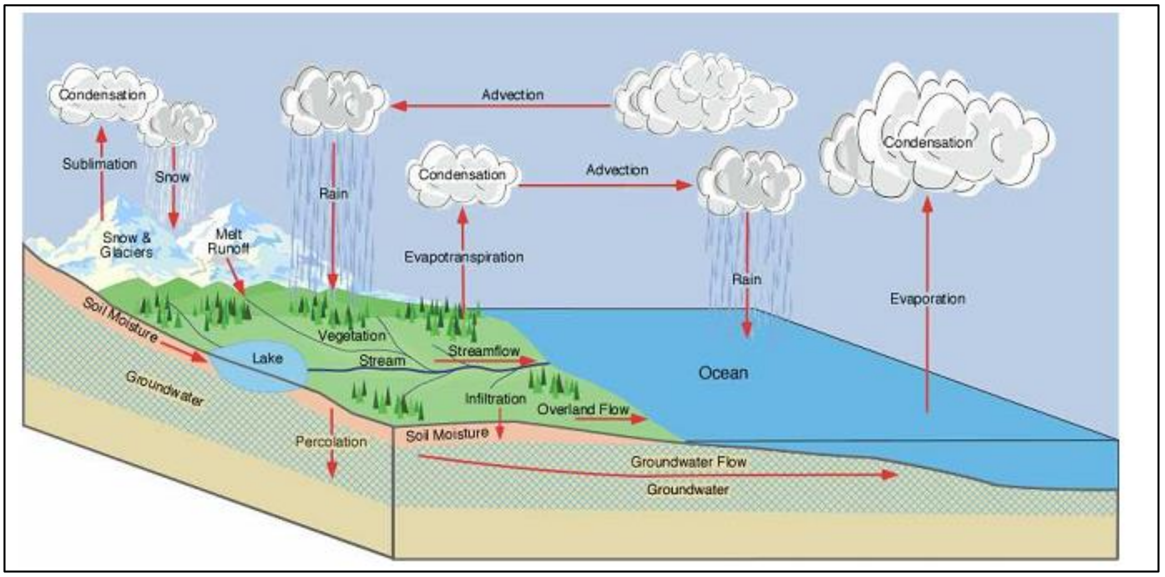


Figure 2. 1 Hydrologic cycle

The basis of generating rainfall-runoff processes lies in the hydrological cycle. The hydrological cycle can be explained by the interdependence and movement of all forms of water on earth.

It usually is described in terms of six major components which are precipitation, infiltration, evaporation, transpiration, surface runoff and groundwater flow in figure 2.1. While the driving force of this circulation is derived from the radiant energy received from the sun, evaporation can be stated as the start of the cycle. Therefore, the ocean is the earth's principal reservoir; it stores over 97 percent of the terrestrial water. Water evaporates into water vapor, where it contributes to clouds formation in the atmosphere. Here it condensates and may give rise to precipitation (e.g. rainfall or snowfall). In the terrestrial portion of the cycle not all of this precipitation reaches the ground surface because some is intercepted by the vegetation cover or by the surfaces of buildings and other structures, and respectively transpires and evaporates back into the atmosphere. The precipitation reaching the ground surface may then collect in order to form surface runoff, it may infiltrate into the ground or it evaporates back up into the sky.

After infiltration of the precipitation into the soil, the flow process becomes very unpredictable since the catchment runoff behavior is closely related to the subsurface physiographic, geometry and geology.

2.2 Classification of Hydrological Model and Model Selection

Models are representation of a portion of the natural or human constructed world which produces an output or series of outputs in response of an input or series of inputs. There are different types of hydrological models used nowadays that range from simple conceptual models up to more complex models. The diagram shown in figure is about the types of hydrological models that can be used for different purposes.

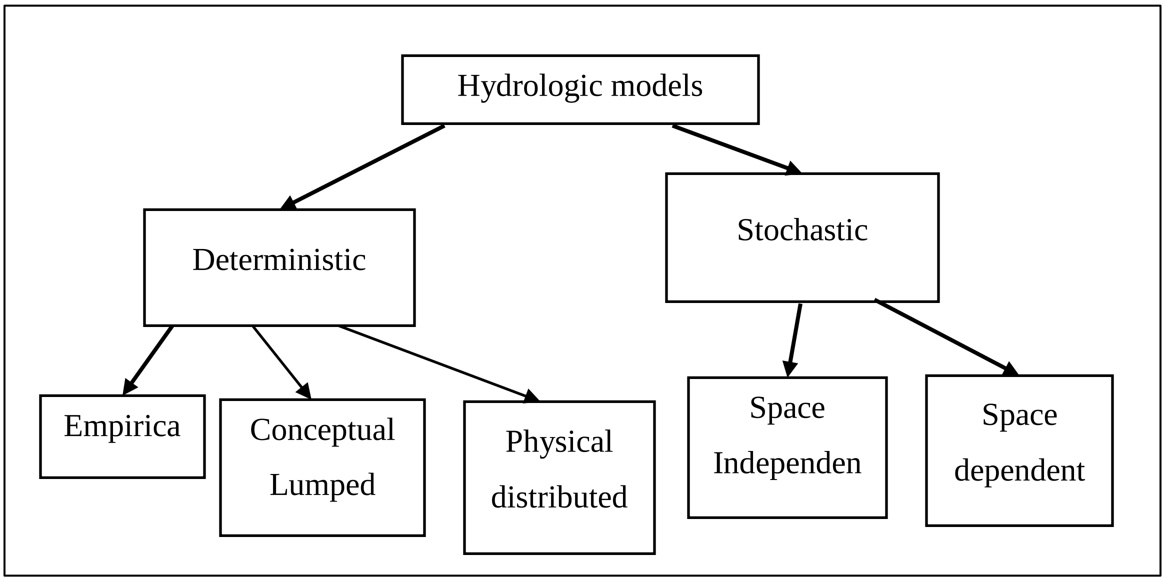


Figure 2. 2 Classification of hydrologic models (Loucks et al,1981)

2.2.1 Selection of Appropriate Model

Selection of an appropriate model depends on the objectives of the study, function and level of spatial and temporal resolution. The criterion is also related to the nature of the problem being investigated and the resources available (Loucks et al,1981).

- ✓ Objectives of the analysis
- ✓ Data requirements
- ✓ Time, money and computational facilities
- ✓ The modelers knowledge and skills

The number of water resources models available has increased in recent years so much that it now a relatively hard task to choose from amongst them. Some of the reasons for modeling a hydrological system include: -

- ✓ To make efficient and cost effective quantitative estimates of water related variables at ungauged locations under varying climatic and land use conditions.
- ✓ To generate useful information from limited or missing data or to replace inaccurate data.
- ✓ To synthesis hydrological data and hence assist in producing coherent and holistic view of the behavior of the entire system.
- ✓ To prove the economic justification of a project and optimize the design of a water resources system
- ✓ To identify and evaluate alternatives, trade-offs, objectives and interests
- ✓ To predict impacts and important assumptions on water resources
- ✓ To enhance judgments on water resources issues (Schulze and RE ,1995)

In generally speaking, reservoir inflow forecasting techniques falls into three categories: time-series models, regression models, and conceptual models.

- ➢ For the purpose of real-time inflow prediction to the Gilgel –Gibe reservoir, the HVB –light model – a conceptual precipitation runoff model was selected due to model is widely applied hydrologic model in Ethiopia as reviewed from many researches done as follows:
- ➢ Characterization of the Regional Variability of Seasonal Water Balances within the Omo-Gibe River Basin; On this study, the water balances of 21 catchments in the basin using an HBV light conceptual model of catchment hydrology with a single linear reservoir were analyzed. Calibrated the model against observed stream flow time series, and it showed good performance for calibrated catchments (Adanech.Y et al,2015).
- ➢ Analyzing the impact of climate change on extreme seasonal flow using appropriate model within in the Omo-Gibe River Basin;

  Intercomparison of three hydrological models, HBV, IHECRAS, and HEC-HMS carried out on the main hydrological gauging station of great gibe and gojeb catchment for selecting the best achieved which later used for analyzing the impact of climate change.

The study recommended that HBV model is the appropriate amid the selected conceptual models for runoff prediction (Zerihun and Kassa ,2012).

- Performance comparison of conceptual rainfall-runoff models on mugger catchment (Abbay river basin); study adopted by SMAR and HBV and found with good performance result for both models (Kumela ,2011).

2.2.2 Hydrologiska Byråns Vattenbalansavdelning (HBV-Light)

The HBV model is a semi-distributed conceptual rainfall-runoff model. It simulates stream flow using rainfall, temperature and potential evapotranspiration (PET) as input. HBV-Light version 3.0 (Seibert, 2005) is recent version of the model widely employed in several studies. The model has 12 parameters that need to parameterize for calibration. Monte-Carlo (MC) simulations can be performed using random numbers from a uniform distribution with in the set ranges for each parameter. The model is subdivided into routines; Snow and glaciers routine, soil moisture routine and runoff routine.

The snow routine uses a temperature-index method to calculate snow and ice melt. Input data are daily air temperature and precipitation. Changes in precipitation and temperature with elevation are calculated using the two parameters PCALT (%/100) and TCALT (^{o}C/100m).The output is the effective precipitation as rainfall and snowmelt which is fed as input into the soil moisture routine. The liquid and solid precipitations are separated using the parameter (TT). snowmelt is amount in any time step is calculated as the product of the degree- factor (Cfmax) and the difference between air temperature and TT, if the air temperature is above TT.

Output of the snow and glaciers routine is the input into the soil moisture routine which calculates soil moisture storage, infiltration and percolation through the soil. The maximum storage capacity of the soil is determined by the parameter FC (field capacity). Infiltration is calculated as a function of the ratio between actual soil moisture and FC.Parameter BETA accounts for different infiltration characteristics of soils. The smaller the BETA, the more water is sent to the next routine event when soil moisture is small as compared to FC. The routine calculates actual evaporation as a function of the parameter LP (fraction of soil moisture storage above which actual evaporation is supposed to be potential evaporation).

The model of the single linear reservoir is used for runoff generation.it is a simple catchment description where runoff at any time is assumed to be proportional to the soil water storage at that time step.

1. The “snow routine” As the area under the study is not located in the tropical climate with no snow experience; the snow routine part of the model has not been used for the study.
2. .The “soil routine” is a process where rainfall goes to the root zone and to groundwater as recharge depending on the relation between field capacity (FC[mm]) and moisture content in the root zone (SM[mm]) (Equation., Appendix-A), and actual evaporation is estimated depending on soil moisture availability using the relation between SM and FC (Equation , Appendix-A).
3. The “response routine” is for computing runoff from upper (SUZ*mm+) and lower (SLZ[mm]) groundwater boxes as the sum of two or three linear outflow equations depending on a threshold parameter, UZL[mm] (Equation, Appendix-A).
4. The “routing routine” is used to transform runoff to simulated runoff (mm/day) (Equations Appendix-A) using a triangular weighting function defined by the parameter MAXBAS (Seibert, 2005).

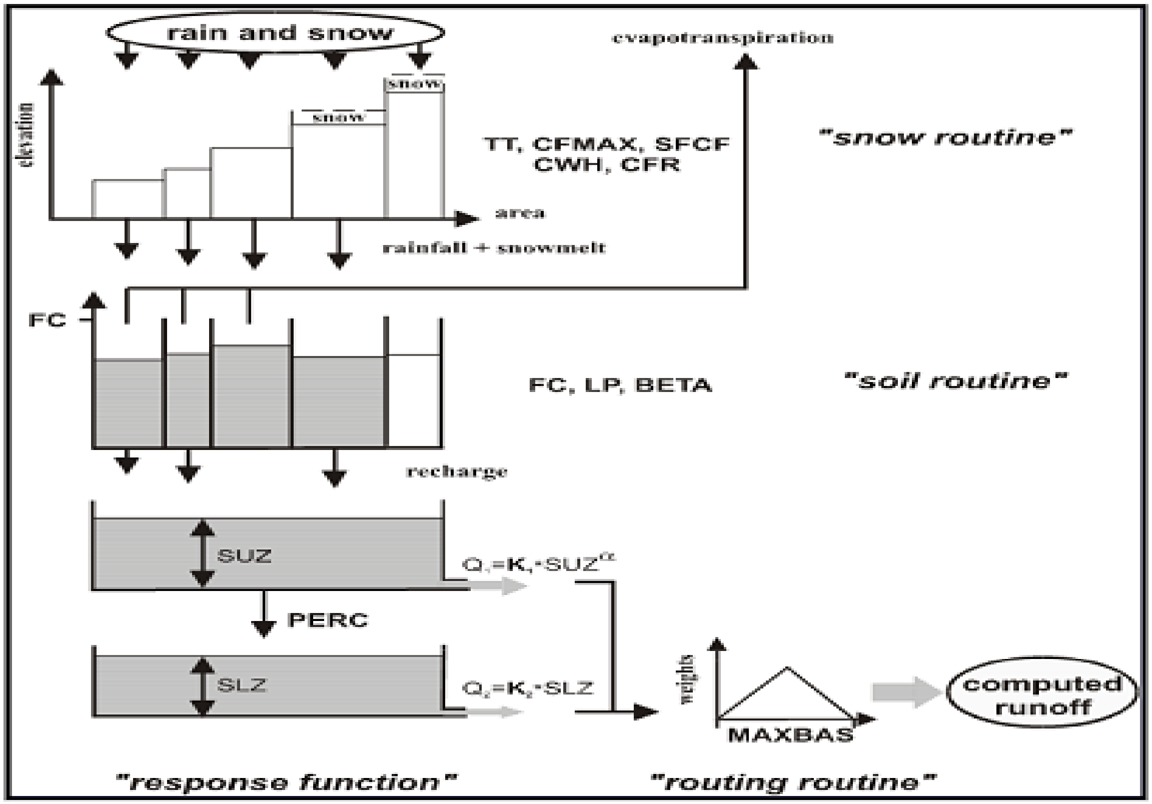


Figure 2. 3 General structure of the HBV model (Seibert, 2005)

Where:

SUZ = Storage in soil upper zone [mm]

SLZ = Storage in soil lower zone [mm]

UZL = Threshold parameter [mm]

PERC = Maximum percolation to the soil lower zone [mm/d]

Ki = Recession coefficient [1/d]

Qi = Runoff component [mm/d]

FC=Field capacity, maximum soil moisture storage

MAXBAS= triangular weighting function (mm/d)

BETA= Factors accounting for different infiltration characteristics of soils

LP=Factor limiting potential evapotranspiration

2.3 Uncertainty in Hydrologic Modeling

Conceptual hydrological models are popular tools for simulating the land phase of the hydrological cycle. They are frequently used for water balance analysis, extending and infilling stream flow records, flow forecasting, reservoir operation, water supply, and watershed management. When parameter calibration is employed, it is easy to show that multiple calibration periods yield multiple optimum parameter sets, and even in a single period, different sets of optimum parameter values may yield similar model performances; this is termed as ‘‘equifinality” in the literature. Consequently, attention should be paid to the uncertainties in hydrological modeling.

For a model to be useful in prediction, the values of the parameters need to accurately reflect the invariant properties of the components of the underlying system they represent. Unfortunately, in watershed hydrology many of the parameters can generally not be measured directly, but can only be meaningfully derived through calibration against a historical record of stream flow data.

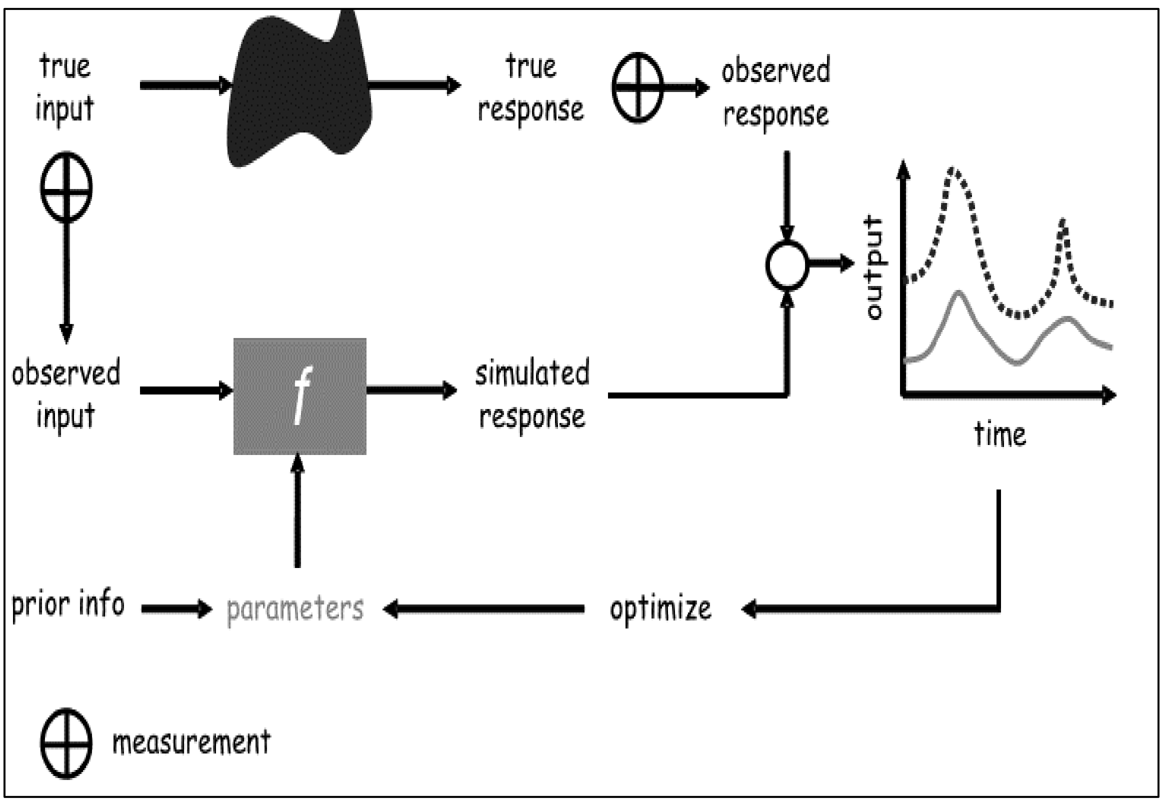


Figure 2. 4 Overview of the resulting model calibration problem

2.3.1 Source of Uncertainty

Estimating the total uncertainty inherent to a hydrological model involves the identification and quantification of four sources: natural uncertainties, data uncertainties, model parameter uncertainties, and model structure uncertainties.

2.3.1.1 Natural Uncertainties

This describes the uncertainty arising from natural random effects which includes the random temporal and spatial fluctuation that always affects the physical process of runoff generation (Melching and Singh ,1995). The extent to which we can describe natural uncertainties depends on the quality and the type of available data for describing the random effects (Guo et al,2004). For example, a dense rain gauge network or radar rainfall data, may allow much of the spatial randomness of rainfall to be observed and explicitly represented, reducing input uncertainty (and potentially therefore structural and parameter uncertainty)**.**

2.3.1.2 Data Uncertainties

The importance of uncertainty in the data (for instance, due to inadequate quality control) may depend on whether the model parameters are determined from calibration or from physical measurements and principles. For instance, (Oudin et al,2006) showed that systematic errors and uncertainties in rainfall data were transferred to the parameters of the model as bias in the parameters. The reason is that the calibration provides an adjustment factor able to compensate for errors and bias.

2.3.1.3 Model Parameter Uncertainties

Known also as model specification uncertainty, this relates to the inability to converge to a single best parameter set using available data, which leads to parameter identifiability problems (Beven, 2001, Wagener et al., 2004).

2.3.1.4 Model Structure Uncertainties

In hydrological applications, consideration of hydrological processes and their mathematical representations leads to the selection of a model structure. However, this structure is controlled by our understanding of the hydrological system, which is determined by the data available. Hence other unobserved processes are usually ignored, introducing uncertainties to modeling results.

2.3.2 Uncertainty Analysis Methods

Calibration refers to the process of adjusting coefficients in model equations, known as model parameters, to fit data observations. In the most basic sense, a good visual fit to the data might be achievable by manually adjusting model parameters by trial and error. On the other hand, a so-called best-fit might be accomplished with an automatic calibration algorithm that seeks to optimize a calculated performance index expressing the difference between simulated and observed values. The results of such methods are deterministic, in that they yield single-valued best-fit parameter sets that were dependent on the measure used and a corresponding single set of predictions.

Uncertainty analysis, such as confidence intervals on linear regression parameters, has been a staple of statistical model building (Johnson ,2005) but has also been historically limited in application to more complex models due to computational and methodological impediments. However, pioneering work by (Hornberger and Spear ,1981) used Monte Carlo procedures with sensitivity analysis on a hydrological model to advance the notion that we do not know all we need to know (and may never) to justify deterministic calibrations and perspectives. Uncertainty analyses yield information on suitable parameter distributions and suitable boundaries on model predictions. In the field of environmental modeling, there are two methodologies for estimating uncertainties in time series modeling these methods are the Generalized Likelihood Uncertainty Estimation (GLUE) and formal Bayesian inference using Markov Chain Monte Carlo (MCMC) analysis.

Both methods are in wide use today (Montanari et al. ,2009). They are both Monte Carlo methods, yet they differ in how they determine acceptable parameter sets and how they sample the parameter space. Both approaches are significantly more advanced than simpler Monte Carlo error-propagation methods, as they both seek to refine knowledge of parameter uncertainty based on the information content in the available data. However, the GLUE method is essentially possibility, while the Bayesian method aims to be probabilistic more detail described in table 2.1.

Table 2. 1 Summary of key ideological and pragmatic differences between the GLUE and Bayesian methods for uncertainty analysis.

Issue	BMCMC	GLUE
Philosophical basis	Optimal exist, but cannot be precisely known	Equifinality; optimal cannot be meaningfully distinguished
Likelihood function	Formal,frequenist	Informal and subjective
Sampling strategy	Focused in region of highest likelihood with MCMC	Random within prior distributions
Key assumptions	Independence, normality, heteroscedasticity in residuals	Error patterns in calibration meaningful to prediction
Error model	Stochastic	Typically not explicit; Errors handled implicitly
Acceptance criteria	Statistical	User defined threshold values
Predictive uncertainties	Probability densities and statics	Non-statistical boundaries
Key issues	error model assumptions; Finding region of global optimal in parameter space	Meaningful acceptance criteria; Inefficient random sampling
Strengths	Probabilistic	No statistical assumptions
Weakness	Results often not as true as purported	No probabilities; Subjective choices must be defended

Source: Methods of Uncertainty Analysis (John Juston, 2010)

Perhaps the strongest philosophical difference between GLUE and formal statistical inference lies in the latter point which is at the core of the GLUE framework.

The GLUE procedure is a basically Monte Carlo method with constraints on the admissible parameters vectors, and is based on the premise that there are many different model structures and many different parameter sets within chosen model structure that may be behavioral or acceptable in reproducing the observed behavior of the system. This concept is called equifinality (Beven and Freer, 2001). Beven (2006) defines equifinality as an inability to meaningfully distinguish one single best parameter set given inherent uncertainties and errors in available data and model structures and typical over parameterization in model equations. The principal of equifinality leads directly to the notion that multiple parameter sets provide equally feasible representations of the system and these parameter sets need not be clustered in a single optimal region of the parameter space (Beven and Freer ,2001) .As a consequence, GLUE tends to employ so-called informal likelihood measures that require no assumptions on the structure of model residuals (Smith & Marshall , 2008). One common example of an informal likelihood measure is the Nash-Sutcliffe model efficiency, given by:

$$R_{eff} = 1 - \frac{\sigma^2_{residual}}{\sigma^2_{observation}} \tag{2.1}$$

This measure has a score of 1.0 for a perfect simulation ($\sigma_{\text{residual}} = 0$) while negative scores indicate the model was a worse predictor than the mean of the observed data. The parameter space is sampled over the whole feasible range and the errors between simulated model results and observations are used to derive the parameter weighting. The behavioral thresholds for both criteria are selected following the model performance in the calibration period. The choice of high threshold values results in narrow confidence limits of the predictions and (usually) a small behavioral parameter set. However, when the chosen is too high, the 0.95 confidence limit do not include 95% of the observations. On the other hand, too low a threshold value will result in too wide confidence limits.

2.4 Reservoir Simulation and Tools

2.4.1 The Concept of Reservoir Simulation

River water flow varies with time and hence water is stored in reservoirs when available in plenty and used later. Reservoir operation studies aim for reliable supply of water for various uses like municipal requirement, irrigation requirement, hydropower generation requirements, flood control and recreation storage requirement in the reservoir. Basically the reservoir operation studies answer the questions ‘when to release?’ and ‘how much to release?’ The common decision making techniques that have been used in the past in relation to reservoir operation are based on simulation and mathematical programming methods such as linear programming (LP) and dynamic programming (DP) (Yeh ,1985).

Simulation, optimization and associated stochastic analysis methods are essential tools in developing a quantitative analysis of a variety of water resource problems for both systems planning and operation. Among these, optimization and simulation (prescriptive and descriptive) are extensively used in water resources problem. Simulation models are descriptive, and demonstrate what will happen if specified decisions are made. Optimization models are generally viewed as being prescriptive. However, a descriptive reservoir system simulation model may incorporate an optimization algorithm. Likewise, a simulation model may be embedded within a prescriptive optimization model. Often the assessment of system performance can best be addressed with simulation models.

Simulation is a modeling technique that is used to predict the behavior of the system under a given set of conditions, representing all the characteristics of the system largely by a mathematical or algebraic description Yeh (1985). Simulation models are used to evaluate the consequences of a set of decisions (what-if analysis) over a hydrologic period of interest.

The operation rule in a complex system involving many projects and purposes of development in a river basin system may be tested with the aid of simulation models. In a pure simulation model, reservoir releases are determined by a set of predetermined operating rules. Through a series of simulations these rules can be modified and improved until model results are judged acceptable. A reservoir system simulation model is based on a mass-balance accounting procedure for tracking the movement of water through a reservoir-stream system, and performed by repeatedly solving the storage equation for a reservoir (inflow minus outflow equals change in storage) over a certain period

2.4.2 Reservoir Simulation Tools

Simulation models remain the primary tool for river basin planning and management studies in practice. Simulation models have been routinely applied for many years by water resources development agencies responsible for planning, construction, and operation of reservoir projects. List and description of few are below:

HEC-5 program simulates the sequential period-by-period operation of a multiple-purpose reservoir system for inputted sequences of unregulated stream flows and reservoir evaporation rates (http://www.hec.usace.army.mil/).Multiple reservoirs can be located in essentially any stream tributary configuration. The program uses a variable time interval. For example, monthly or weekly data might be used during periods of normal or low flows in combination with daily or hourly data during flood events. The user specifies the operating rules in HEC-5 by inputting reservoir storage zones, diversion and minimum in stream flow targets, and allowable flood flows.

The Acres Reservoir Simulation Program (ARSP) was developed by Acres International The original model was developed to assess alternative operation policies for a 48-reservoir multiple-purpose water supply, hydropower, and flood control system in the Trent River Basin in Ontario, Canada(http://civilcentral.com/html/arsp_tech_info.html). The ARSP network flow programming based model simulates multi-purpose, multi-reservoir systems. Operating policies are defined by prioritizing water demands. Monthly, weekly, daily, or hourly time steps may be used. The software assigns upper and lower bounds and cost functions to the network flow paths for the network flow programming formulation based on the input provided by the user.

The Water Evaluation and Planning (WEAP) was developed and is distributed by the Stockholm Environmental Institute Boston Center at the Tellus Institute located in Boston,Massachusetts (StockholmEnvironmentInstitute,ttp://weap21.org).
WEAP is a reservoir/river/use system water balance accounting model that allocates water from surface and groundwater sources to different types of demands. The Modeling system is designed as a tool for maintaining water balance databases, generating water Management scenarios, and performing policy analysis.

The Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers has developed a new reservoir simulation(HEC-ResSim) as the successor to the well-known HEC-5 (http://www.hec.usace.army.mil/).
HEC-ResSim uses an original rule-based approach to mimic the actual decision-making process that reservoir operators must use to meet operating requirements for flood control, power generation, water supply, and environmental quality. Parameters that may influence flow requirements at a reservoir include time of year, hydrologic conditions, water

temperature, and simultaneous operations by other reservoirs in a system. Basic reservoir operating goals are defined by flexible at-site and downstream control functions and multi-reservoir system constraints.

As HEC-ResSim has evolved, advanced features such as outlet prioritization, scripted state variables, and conditional logic have made it possible to model more complex systems and operational requirements, as a result of unique features mentioned it is primarily selected for this study.

It has a graphical user interface (GUI) and utilizes the HEC Data Storage System (HECDSS) for storage and retrieval of input and output time-series data. ResSim is used to simulate reservoir operations including all characteristics of a reservoir and channel routing downstream. The model allows the user to define alternatives and run their simulations simultaneously to compare results. Network elements include reservoirs, routing reaches, diversions, and junctions. In ResSim, watersheds include streams, projects (i.e. reservoir, levees), gage locations, impact areas, time-series locations and hydrologic and hydraulic data for that specific area.

Schematic elements in ResSim allow to represent watershed, reservoir network and simulation data visually in a geo-referenced context that interacts with associated data. The program is organized in to three modules namely watershed setup, reservoir network and simulation. The basic feature of the model in each of the modules is shown in figure 2.5 the watershed setup module helps the simulator to define the various elements of the river system including the streamlines, the dams and the diversion structures. The reservoir network module is where the reaches are defined and the physical characteristics related to the dam, its reservoir and the outlet works are inputted. The simulation module performs the simulation using inputs defined in the watershed setup and the reservoir network. The various input data fed to the system are listed in the following section

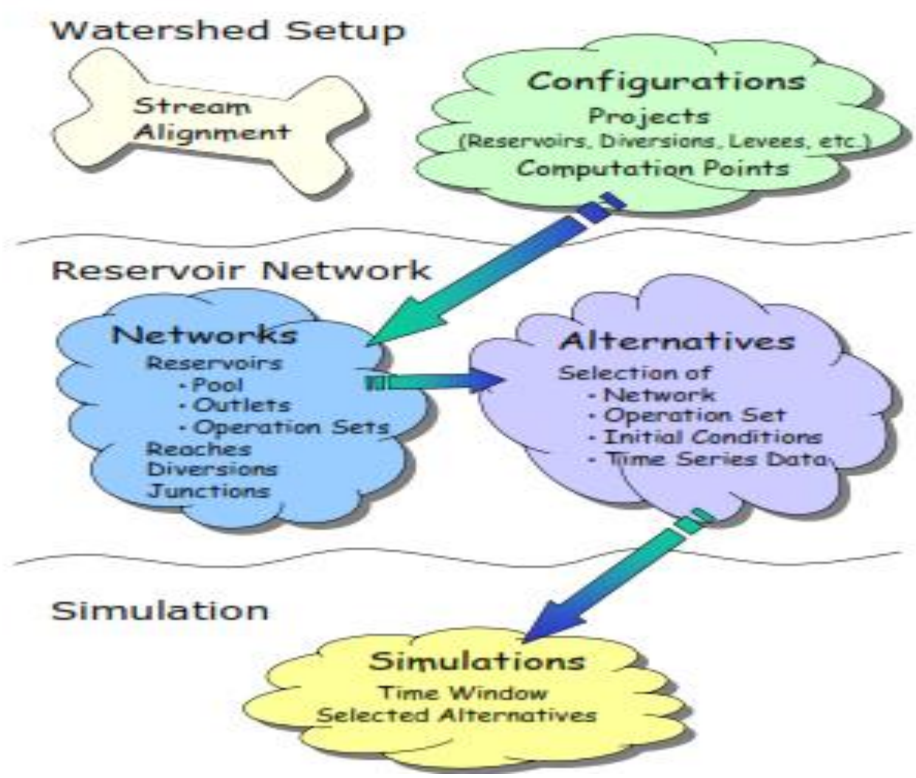


Figure 2. 5 Model features in each of the three modules of HEC-ReSsim (2013)

The watershed setup is where every component of the model is defined. Here the simulator defines the streamlines, the reservoir, the diversion works along with their relative positions and arrangements. Figure2.5 shows the model setup in the watershed module. This has been done in as a first step taking in to account the major components associated with the dam. In watershed setup, the arrangement river does not need to be geo-referenced neither it exact shape be drawn. The software only requires the physical information pertaining to each component (the dam, reservoir, spillway, outlet works etc…) be defined. That is the only way the system recognizes the components.

The purpose of the Reservoir Network module is to isolate the development of the reservoir model from the output analysis. This module facilitates the creation of the network schematic, the description of the physical and operational elements of the reservoir model, and the definition the management alternatives to be analyzed. Reservoirs are further divided into multiple technical elements such the pool, the dam, and one or more outlets. The criteria for reservoir release decisions are drawn from a set of discrete pool heights, power production levels and release rules. Reservoirs are connected to the river network as well diversions or junctions. After completing the connection network schematic, physical and operational data for each network element are defined. Management alternatives are created to compare results using different model schematics, i.e. Physical properties, operation sets, inflows, and/or initial conditions. The purpose of the simulation module is to isolate the output analysis from the model development process. Once the reservoir model is complete and the alternatives have been defined, the Simulation module enables the model to test various river flow hypotheses.

2.4.3 Reservoir Operation Rules

Reservoir operation rules provide a guideline for answering the questions on how the storage should be managed, more in particular given a certain status of the reservoir how much water should be released during the coming time step. Reservoir management requires the creation of "a set of operation (or regulation or release) procedures, rules, schedules, policy or plans that best meet a set of objectives". Typically, reservoir operating rules guide release decisions. Operational decisions involve allocation of storage capacity and water releases between reservoirs and between uses in different time periods.

The wide variety of regulation policies presently in use consist of operating rules which specify ideal pool levels or zones, and specify what to do if reservoir storage deviates from those levels or zones. Typically, reservoir storage capacity is subdivided in several zones or pools, such as inactive-, conservation-, flood control- and surcharge zone figure 2.6. The "Guide Curve "figure specifies the reservoir level at which the model itself tries to keep the water surface when there is no defined rule by the modeler. A guide curve operation oversees releases to maintain that storage level. The general release operation is to:

i. release water as quickly as possible when high inflows encroach into the flood pool and raise storage above the guide curve, or
ii. Curtail releases to the minimum required amounts necessary to satisfy conservation requirements when inflows are low and storage level is drawn down below the guide curve. As inflows decrease (after flood pool encroachment) or inflows rise (after draw- down into conservation pools), guide curve operations tends to guide storage level back towards the "Guide Curve."

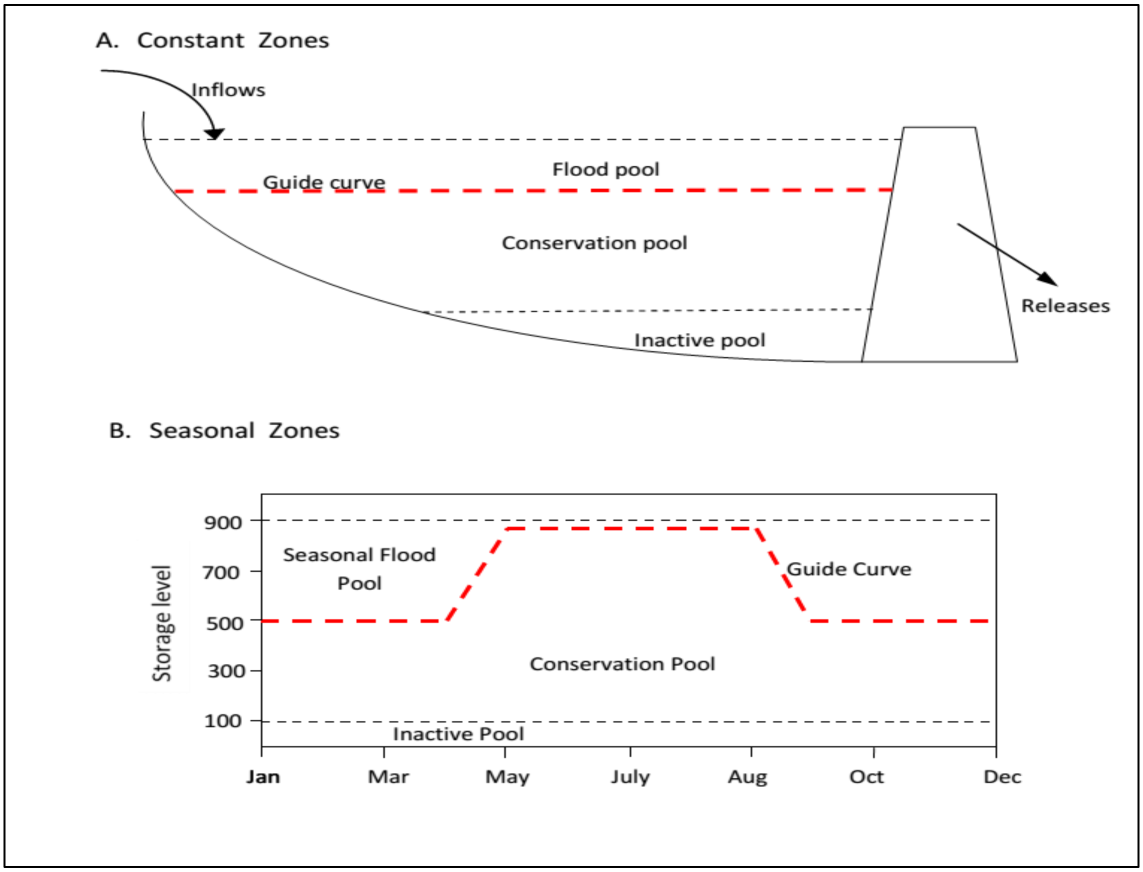


Figure 2. 6 Reservoir storages partitioned into zones

A reservoir in HEC-ResSim must have a target elevation. A reservoir's target elevation, represented as a function of time, is called its Guide Curve. Itis the dividing line between the upper zones of the reservoir (typically called the flood-control pool) and the lower zones (typically called the conservation pool). The release decision logic in HEC-ResSim starts and ends with the guide curve. When the reservoir's pool elevation is above the guide curve ("in flood control"), the reservoir wants to release more water than is entering the pool; when below guide curve ("in conservation"), and the reservoir wants to release less water than is entering the pool. All operating rules and physical limitations act as constraints upon the reservoir's ability to meet the goal of returning the pool to its guide curve elevation. Without rules, the reservoir will be constrained only by physical capacity of the outlets to get to and stay at the guide curve elevation (HEC, 2013).Generally reservoir operation rule catagorized ito rules of pool,rules for dam and outlet groupes,rules for power plant and pum works.

2.5 Reservoir Performance Evaluation Indicators

Pressure on effective management with the surface water resources will become stronger and stronger. Possibilities how to face these challenges are a lot. Efficient and secure utilization of storage water in reservoir as well as effective water supply distribution and water resources planning is need evaluation by using a various simulation and optimization techniques.

The question of whether a system operates in a satisfactory way is of high importance for engineers and planners (McMahon et al.,2007) for a brief history of reservoir storage–yield analysis). In water resource management, one of the most frequently task for hydrologist is to evaluate the performance of a reservoir under current conditions or different reservoir operations policies (Xu et al.,1998).

Generally, performance evaluation of water resources system is specified as reliability, Vurneabilty, Resiliency or Risk. Reliability characterizes the frequency of failures (here as the percentage of time that the water supply system can provide a contracted demand), Resilience the speed of recovery from a failure and Vulnerability the severity of failures, respectively.

The definition of a failure event is the key-main point to be addressed before applying the RRV concept. Variables with available records characterizing the system have to be identified first and failure is expressed objectively in terms of critical thresholds (constant or varying with time). In the context of reservoirs management, a failure occurs when the water supply system is unable to meet a given water demand.

The common use of simulation models of water supply systems has led to the development of performance measures, which quantify the characteristics of system behavior. In the following, the literature review was focused on water management issues and cited references are mainly related to reservoir performance assessment.

Reliability(R)

Reliability criteria are probably the most used performance measures for water supply system designing (particularly to determine capacity regarding the target water demand).

Reliability is linked to the probability that a system will correctly deliver services as expected by users (or, complementarily, to the probability of failure)". Thus, reliability can

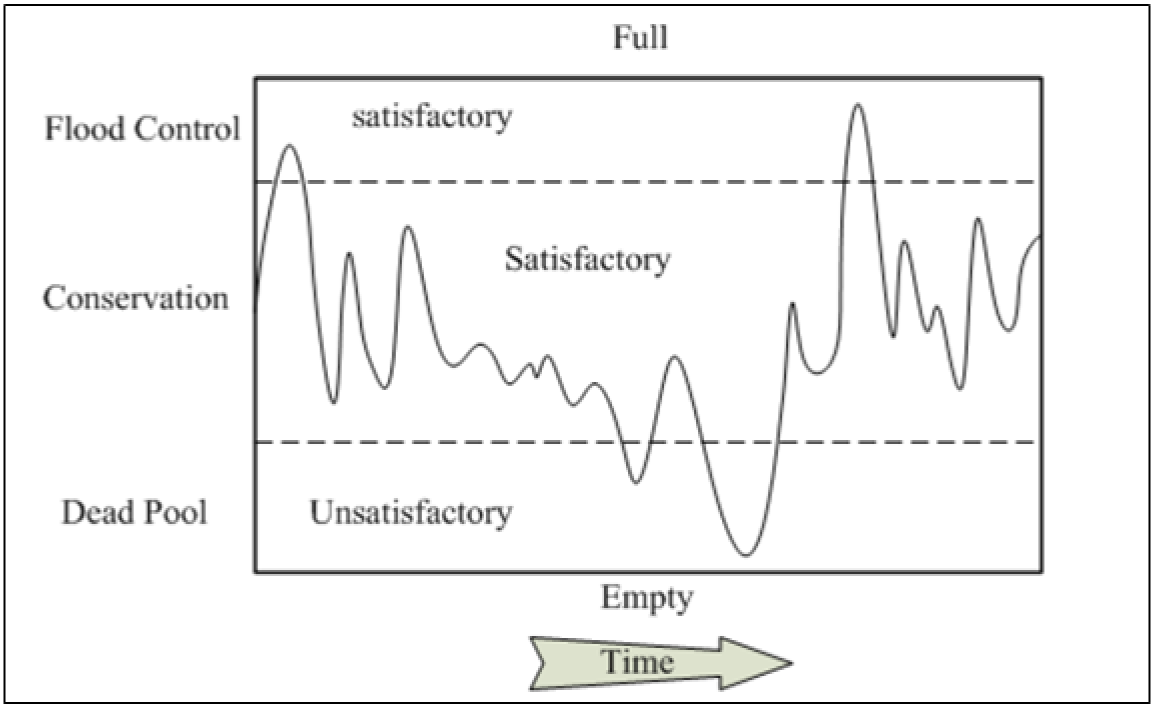


Figure 2. 7 Satisfactory and unsatisfactory states based on the water volume in reservoir

be interpreted as the opposite of the probability of failure.

Probability of the system to be /proportion of the time in a satisfactory state at different temporal resolution (time based resilience, also occurrence reliability (Hashimoto et al.,1982) is given by

$$\mathrm{Re}l = \sum_{t=1}^{Ntot} Zd(t) \Big/ Ntot \qquad (2.2a)$$

$$\mathrm{Re}l = \sum_{t=1}^{Ntot,d} Zd(i) \Big/ Ntot,d \qquad (2.2b)$$

(d= 1 month and d=1 year are commonly adopted) where. N is the total number of intervals. Every water resources have a defined satisfactory range (S) and unsatisfactory (U) for related criteria (C). If Xt > C then Xt €S and Zt=1, else Xt¸€U and Zt=0. But, another criterion was defined is Wt that show a transform from un-satisfaction to satisfaction. Proportion of released water to the total water demand (volumetric resilience, also quantity based reliability) (Kjeldsen and Rosbjerg .,2004) is given by:

$$\mathrm{Re}\,l = 1 - \sum^{Ntot} \max(0, C(t) - x(t)) \Big/ \sum_{t=1}^{Ntot} C(t) \qquad (2.2$$

Resiliency (R)

Resilience was first introduced by (Holling, 1973) in ecology to measure the capacity of an ecosystem to face changes and to persist after stress. This definition has been extended since then (Brand and Jax ,2007) for a recent review) to achieve sustainability.

Conditional probability to migrate from a state of failure observed at t to a satisfactory state at the following time step t+1((Hashimoto et al. 1982, McMahon et al., 2006).

$$\mathrm{Re}\,s = NF \Big/ \sum_{t=1}^{Ntot} ((1 - Z(t)) = 1 \Big/ mean(dur(i), i = 1, ...NF) \qquad (2.3a)$$

Maximal duration of failure event (Moy, et al., 1986)

$$\mathrm{Re}\,s = \max(dur(i), i = 1, ...NF \qquad (2.3b)$$

Inverse of the maximal duration of failure event to make this criterion comparable to the definition suggested by (Hashimoto et al. 1982 and Kjeldsen and Rosbjerg, 2004).

$$\mathrm{Re}\,s = 1 \Big/ \max(dur(i), i = 1, ...NF \qquad (2.3d)$$

Ratio of the minimum release (in the case of a constant target demand D and a minimum release R constant for each failure event) (McMahon et al., 2006).

$$\mathrm{Re}\,s = R\min \Big/ DF \qquad (2.3e)$$

Vulnerability

Vulnerability defined by (Hashimoto et al., 1982) refers to "the likely magnitude of a failure, if one occurs".

$$Vur = \sum_{j=1}^{NF} f(h(j)h(j) \qquad (2.4a)$$

Where, h (j) is the most severe outcome of the j_{th} failure even and f (h (j)) is the cumulated probability related to h (j)

Maximum of NF cumulative deficits (Moy et al.1986)

$$Vur = \max(Di), i = 1..........NF) \qquad (2.4b)$$

Mean of NF cumulative deficits (Kjeldsen and Rosbjerg, 2004)

$$Vur = Mean(D(i), i = 1,......NF) \quad (2.4c)$$

Ratio of the maximum shortage to the target demand (in the case of a constant target demand D and a maximum shortage S constant for each failure event) (McMahon et al.,2007).

$$Vur = S/_{DF} \quad (2.4d)$$

Conditional mean déficit (Vogel, et al., 1999)

$$Vur = mean\left(D(i)/_{dur(i)},........, NF \right) \quad (2.4e)$$

Standardized mean cumulated deficit (in the case of a constant target demand DF) (McMahon et al., 2006).

$$Vur = mean^{(D(i),......, NF)}/_{DF} \quad (2.4f)$$

For a given storage capacity, the resilience is expected to monotonically decrease as water demand increases whereas vulnerability is expected to increase. Changes in RVV criteria have been examined against changes in both storage capacity and water demand. (McMahon et al., 2006) found that Resilience and Vulnerability criteria decrease as inflow variability increases. For a given draft, Resilience was found to increase with reservoir size. However both Vul (2.4b) and Res (2.4c) are not be very sensitive to changes in storage capacity when the ration of the water demand to the mean annual inflow is high (Jain, 2010).

Resilience is more sensitive to changes in operation policies than Reliability in most cases considered by (Jain & Bhunya, 2008).

2.6 Previous Study in the Study Area

Generally, Gibe -I is one of the potential energy assets of the country producing 184MW with average energy per annum of 722 GWH. Gibe- I is not only the power source but also discharge significant amount of water with rate of 100m^3/se (33.91m^3/se each turbine) which is used for Gibe- II and Gibe -III hydroelectric power as the main source of the tributaries along its way to Gojeb and Omo River. There is a vertical shaft depth of 166m containing three branches (units) manifolds. Each of the unit has rated capacity to produce 70MW and rated water discharge of 33.91 m^3 /se. The three manifolds internal diameter is approximated to 5m, 4.1m, and 2.9m having the maximum estimated pressure of 3.5MPa that uses flowing or falling water to create power by means of a set of paddles mounted around a wheel.

There is concrete lined electric cable shaft connecting to the switch yard of about 175m height above the earth surface. There are set up auto transformer 1*40MVA, 230/132 Kv and the general auto transformer is about 3*73MVA, 13.8/230KV synchronized to Interconnected system of Gedo, Jimma, Sebeta, alibi substations.The transformer takes the alternating current and converts it into higher-voltage current. The electrical current generated in the generators is sent to a wire coil in the transformer. This is electrical energy. The Generators are synchronized directly coupled to vertical shaft and the three Francis turbines with the capacity to produce 73MVA each by a factor of 0.9 power rate. And its estimated speed is about 428.57rpm (EEPCO, 2004)

Reservoir storage of 1.027billionm^3 from draining of catchment area 4250km^2 is allocated for this purpose. Dead storage is 167 Million m^3 and storage equal to 860 million m^3 is reserved for power production. For the storage has standard operating rule within reservoir zones. The top most is flood control zone; this zone has fixed elevation zone from 1672m a.s.l (top of conservation pool) to 1675m a.s.l.

The reservoir water level fluctuates depending on the season, and in the rainy season, the water level of the dam starts to increase and reaches a maximum in September or August and immediate alarm signal at elevation of 1671.23m a.s.l in order to open the gate for spilling of water practiced. Encroachment of storage into the flood control zone not used during which may be used periods in order to provide additional water supply. This reduces total amount of water annually regulated for maximum production, augments low inflow during dry season.

The second is conservation pool, which on the top of dead zone with a fixed elevation between 1653m a.m.s.l (top of dead storage) and 1671.23 a.m.s.l. At the end of September, the water level starts to decline because of decreased river discharges due to low rainfall and reaches minimum water level in May or June as show in figure2.8. Yet for dry season, when inflows are generally low regulation in seasonal time scale could be possible.

This could be possibly reducing the total amount of spills, with beneficial effects such as a higher electricity production and less water shortages.

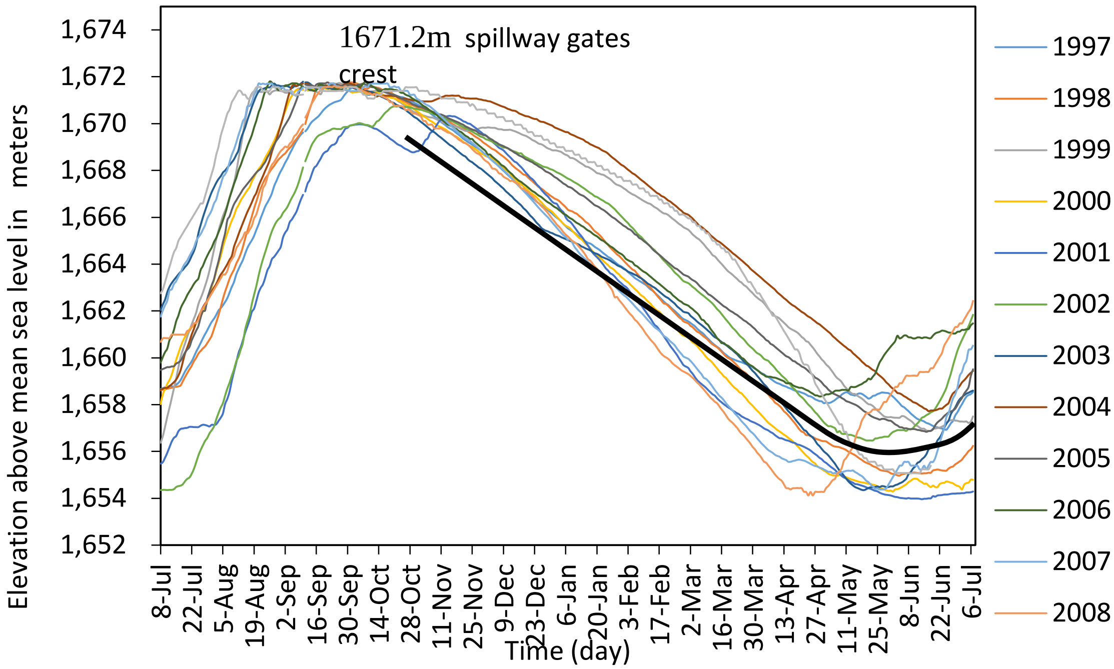


Figure 2. 8 Gibe- I observed reservoir water level

In the past a great deal of research has been conducted in the area of climate change, various hydrologic model of the waters management in the watershed both in the thesis and numerous intuitional research levels. Among numerous studies tried to be referred in search and described below as follows:

The study done on inter-comparison of three hydrological models, HBV, IHECRAS, and HEC-HMS, carried out on the main hydrological gauging station of Great Gibe and Gojeb catchment for selecting the best achieved model for the analysis of climate change scenarios, found an increase of rainfall by 5%, there might be an increase of seasonal maximum flow up to 10.53%, and for an increase of temperature by 4%, there might be a decrease in seasonal maximum flow up to 3.13%, whereas for an increase of both rainfall and temperature by 5%, there might be an increase of seasonal peak flow up to 7.16% (Zerihun and Kassa, 2012).

The study on water use and operation analysis of water resource systems in basin, tried to do without taking into account the effect of a good agreement between measured stream flow and simulated by using hydrograph and data transferring techniques found that average increase of 130% in mean monthly inflows from November to June and decrease of 25% in mean monthly inflows from July to October was observed at Karadus. But the mean annual outflow from the basin at Karadus will be decrease by 1.14% (Daniel ,2011).

The study tried on modeling of cascade dams and reservoirs operation for optimal water use, applied by SWAT model for Gibe III and III basin and estimated the average daily stream inflow to the next three consecutive decades 2001-2010, 2011-2020 and 2021-2031 and showed result of 68.6, 63.0 and 60.8 m3/s, respectively, for the Gibe II reservoir the 521, 552 and 530 m3/s, respectively. From this numbers the study concluded that for Gibe I and Gibe II a slight decrease of inflows for the two future decades is to be expected, whereas for Gibe III a trend is less clear as a large increase of the inflow for the 2011-2020 decade will be followed again by a decrease down to the value close to that one of the past decade. Corresponding numbers are 74.3, 72 and 68.4 m^3/s (Teshome ,2015).

The study on quantifications of dam-induced hydrological alteration in Gilgel Gibe I watershed, investigated the impact of climate variation and human activity particularly Gilgel Gibe dam I construction on total flow of Gilgle Gibe I watershed for pre and post dam construction period, concluded that change in rainfall trends of the Asendabo and Limmu station shows the decreasing trend where the temperature and evaporation of the two stations shown increasing trend which contribute to decrease the stream flow change in watershed but this was statically insignificant (Besho et a.,2017).

Even though these and many hydrological studies done in the catchment as described above, there is great variation of the result by different authors and the problem could be the efficiency of software's, getting the hydro meteorological data in the required quantity and quality in time. This was one of the major limitations to use models. It is usually the case that the data intensive nature of models developed by those studies could limit their application under Ethiopian conditions in general and the Gibe-I basin in particular. The other limitation of the past studies was, the hydrological model uncertainty, since it is not clear how uncertainty in scenario projections might affect the formulation of robust operational rules for reservoir management and the assumption of a single hydrologic model parameter of the watershed during calibration. Therefore, the need of revision of water resources studies on basin and technical assessment of reservoir performance using simulated historical reservoir inflow while considering parametric uncertainty of the hydrologic, reservoir characteristic, data etc. was made available.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

Gilgel Gibe-I project is located in the south-west part of Ethiopia, in Oromia Regional State. The reservoir is located at 7º49’52.45’’ N latitude and 37º19’18.79’’E longitude. The project is purely a hydropower scheme with reservoir live storage capacity of $657x10^6m^3$.The catchment area of the Gilgel Gibe-I basin is about $5125Km^2$ at its confluence with the great River and about $4225Km^2$ at dam site. The Gilgel Gibe basin which drains into the Gibe-I reservoir is located in between 7º19’07.15’’N and 8º12’09.49’’N latitudes and 36º31’42.60’’ E to 37º25’16.05’’E longitudes. The first plant, Gibe-I, is a conventional hydroelectric power plant with a capacity 0f 180MW.Started in 1986 and completed in 2004 (after being interrupted in the early 90’s) was the Ethiopia’s largest power plant.

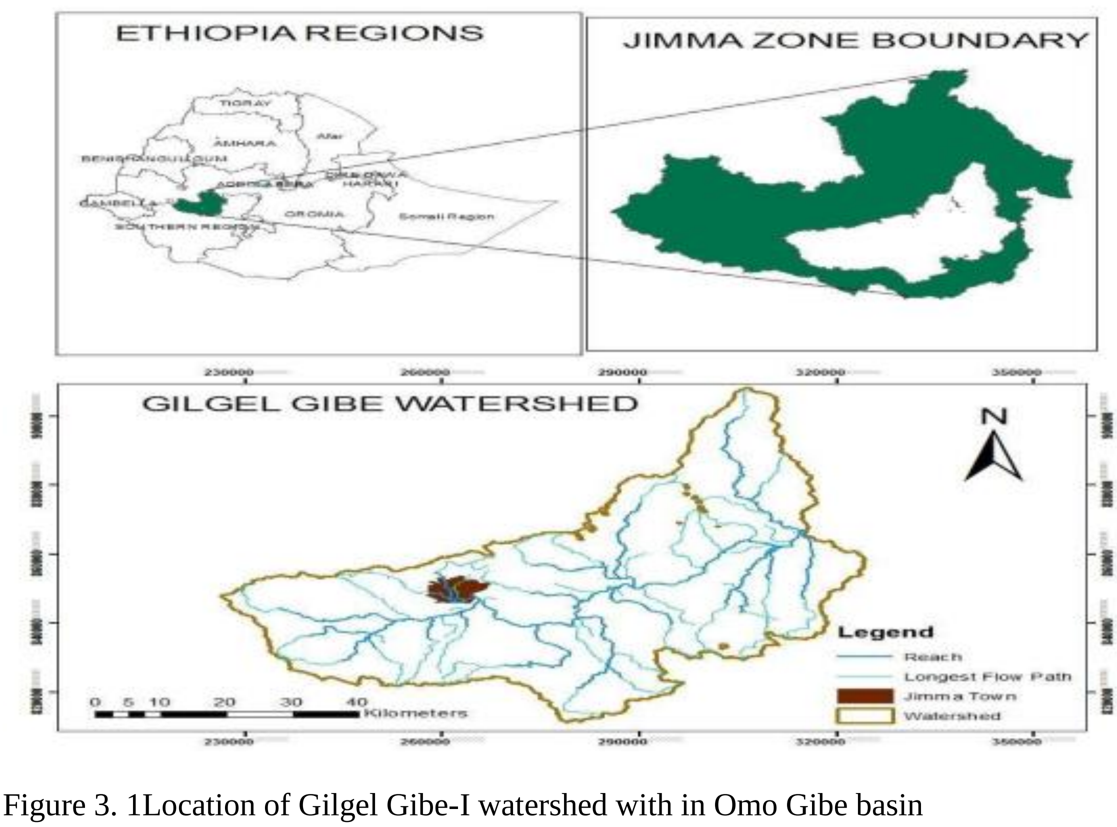


Figure 3. 1Location of Gilgel Gibe-I watershed with in Omo Gibe basin

3.1.2 Topography

In the study area, the upper stretch of the river between Asendabo and the Deneba waterfall presented a winding fairly flat course. The right bank was flat or very slightly hilly at most and left bank was steeper. Approaching the Deneba waterfalls, at approximate elevation 1,620 meter a.s.l, the river banks became steeper. Generally, elevation in the watershed ranges from between 1,079 meters nearly at the dam site to 3,341 m a.s.l.at the highest level figure 3.2.

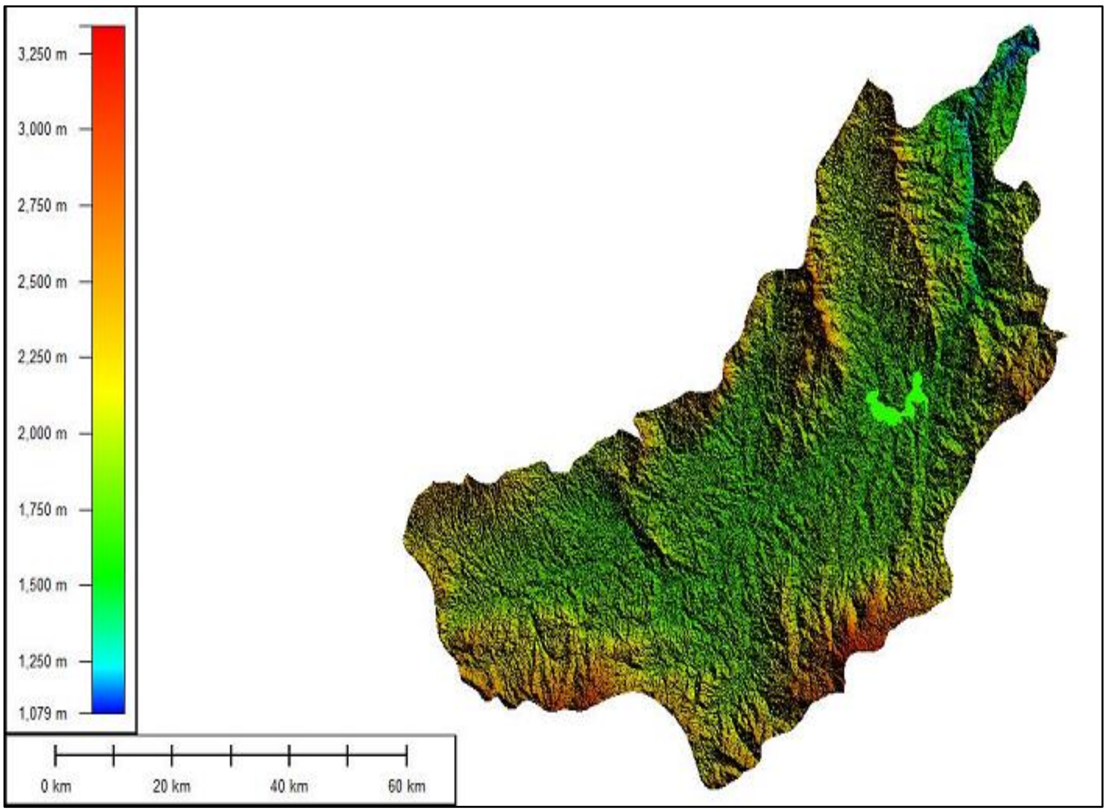


Figure 3. 2Topography of the study area

3.1.3 Climate

The climate in Ethiopia is related to the topography and to the movements of the Inter-Tropical Convergence Zone (ITCZ) during the year. The amount of rainfall (mm) varies with topography and location as shown in figure 3.3.

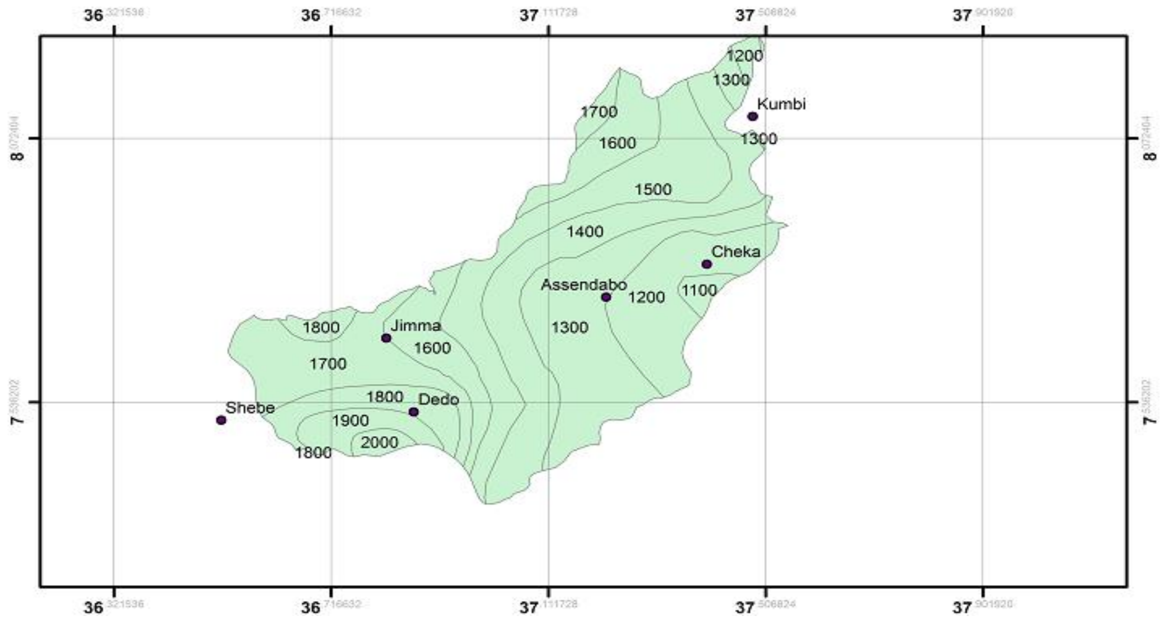


Figure 3. 3 Spatial variation of rainfall in the Gibe-I basin

Rainfall decreases throughout the catchments with a decrease in elevation shown which bi-modal pattern with its maximum is during the summer and minimum during the winter. It appears that 60 percent of the total amount of annual rainfall occurs between June and September, 30 per cent from February to May, and only 10 per cent between October to January. In addition, long term monthly average (1996-2016) rainfall and temperature of the basin shown figure 3.4 and 3.5.

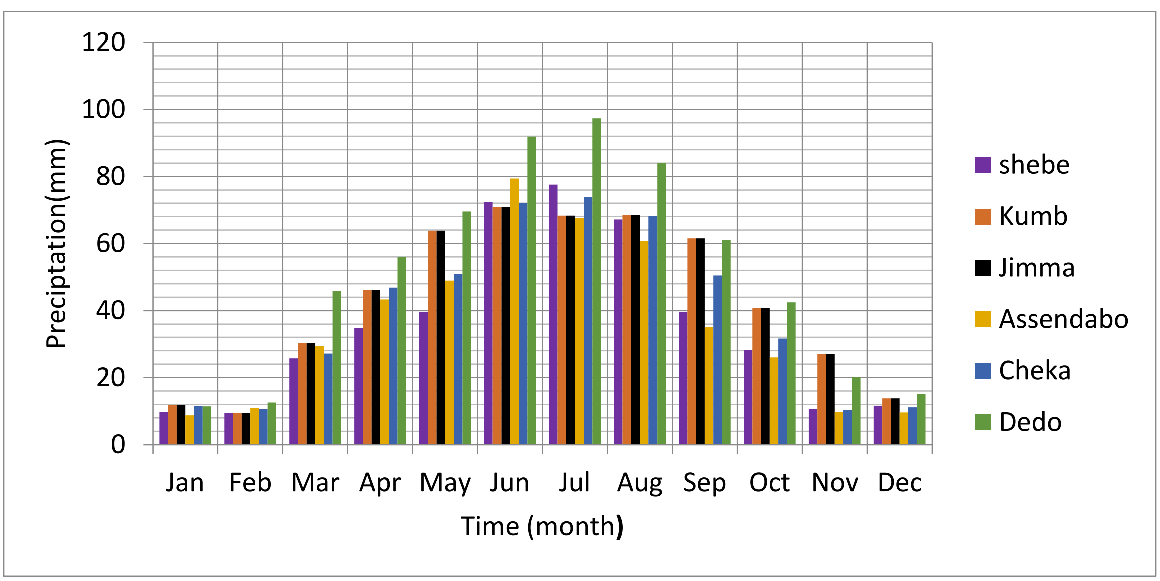


Figure 3. 4 Long term mean rainfall (1996-2016) of the Gibe-I meteorological stations

Temperature is fairly constant throughout the year, an average value of 19 degrees Celsius and with the mean minimum, maximum temperatures shown for station.

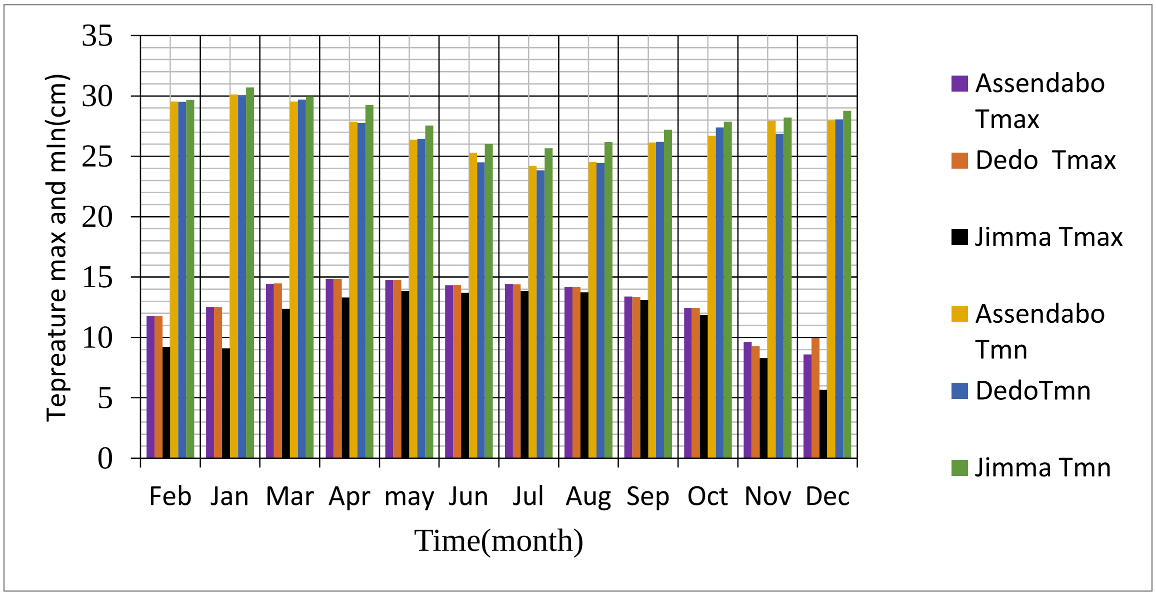


Figure 3. 5Long term mean (1996-2016) maximum and minimum temperature

3.1.4 Geology

The Gilgel Gibe is situated on the southwestern Ethiopian plateau. The area is characterized by a series of basic and subsilicic effusive volcanic rocks, frequently inter-layered with reddish paleosiols of Tertiary age. The rocks of the area are tentatively ordered as following, beginning with the youngest rocks: Trachytic tuff, Vesicular basalt, Aphyric augite basalt, Welded tuff, Augite basalt and Augite trachyt over the upper reservoir, these rocks are covered with fluvio-lacustrine sediments. The entire volcanic sequence is frequently blanketed by thin, residual, subtropical lateritic soils, which have been formed on hill and ridge foot slopes. As well, they are covered with thick, black, plastic clay deposits on the flatter areas and valley.

The hills on the right side of the Gilgel Gibe River, downstream of the waterfalls, are mostly covered to an elevation of about 1,800 m.a..s.l. by thick colluviums deposits together with deeply weathered landslide and/or rockslide material.

3.2 METHODOLOGY

The general methodology in order to accomplish the research study and achieve the objectives, the following flow chart was used.

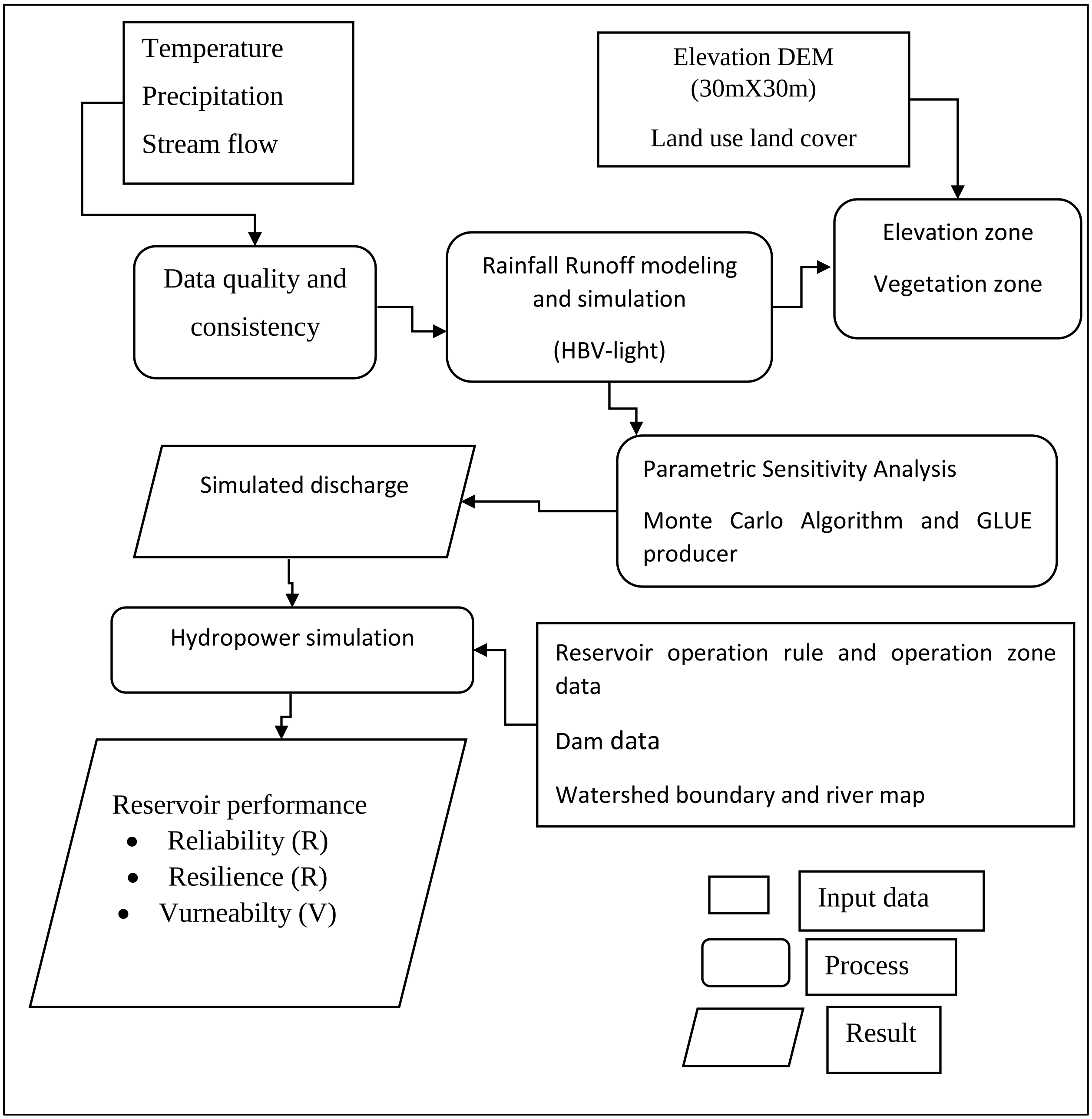


Figure 3. 6 Thesis flow chart

A Conceptual hydrologic model (HBV-light) is applied to simulate reservoir inflow reduced model parametric uncertainty.

The model parametric uncertainty is done by Monte Carlo (MC) optimization tool in the model and parametric sensitivity analysis tested to reduce less sensitive parameters that would minimize over parameterization.

The model is evaluated by percentage of observation data falling with in confidence limit. Reservoir simulation (HEC-ResiSm) applied by using simulated reservoir mean inflow with other necessary data and current operation rules to evaluate technical performance reservoir. Current operation policy of reservoir is evaluated in terms of reservoir reliability, resilience and vulnerability for its designed turbine release and operation.

3.2.1 Data Collection and processing

HBV-light requires input daily precipitation, air temperature, and monthly estimates of potential evapotranspiration as well as daily runoff. These data were collected from National Meteorology Agency (NMA) and Ministry of Water, irrigation and electricity (MoWIE), for the full period 1996–2016.

Reservoir physical properties, power characteristics and rule curve, were collected from Ethiopian Electric power. Land use land cover map and Digital Elevation Model DEM (30mx30m) obtained from the Ministry of water, irrigation and Electricity, Department of Geographical information system. Finally visit was made to the study site to review and collect leakage, seepage maximum and minimum temperature and observed water level, release and production data from year 1996-2016.

3.2.2Visual Inspection

The rainfall stations were chosen, among those available, for their continuous record their length of record for hydrological modeling and quality control for the data analysis. Discontinuities (visual examination) in order to select the representative stations selected based on the percentage of gaps threshold for the whole. For precipitation the cumulative percentage of gaps in the period January 1996 until December 2016 for the selected stations, as tabulated below in the table 3.1.

Table 3. 1 Arranging stations by missing data

Stations	Longitude	Latitude	Elevation	Number of data missed	% missed
Chelekitu	38.53	6.004	1701	606/7671	7.89
Jimma	38.1667	7.66667	1710	442/7671	5.76
Shebe	36.516667	7.5	1813	8376/7671	10.9
Assendabo	37.216667	7.75	1764	910/7671	11.80
Kumb	37.48333	8.11667	1930	716/7671	9.33
Cheka	37.4	7.81667	1934	1000/7671	13.04
Dedo	38.866667	7.51667	2210	948/7671	12.36

Due spatial variation of the meteorological data, for this specific study some station was considered, as shown above table and neighbor stations which have higher missed data are used for data quality control but rejected for study.

3.2.3 Filling Missed Meteorological Data

Continuous time series of precipitation and temperature considerably facilitate and improve the calibration and validation of climate and hydrologic models, used for the planning and management of earth's water resources and for the prognosis of the possible effects of climate change factors dependent from the completeness of the time series data. The following methods was used in order to estimate the missed precipitation and temperature data

I. **Regression Method**

Precipitations are highly influenced by elevation and on the seasonal for the study area. Hence to reduce data input uncertainty while filling data both spatial and temporal simple regression developed in order to handle missing data for station near or adjacent. As there was missing data of Assendo rainfall station found at elevation of 1764m.a.s. l adjacent jimma station found at elevation of 1710m.a.s. l was used. For example, there is missing data August 2008-09-August 2008.

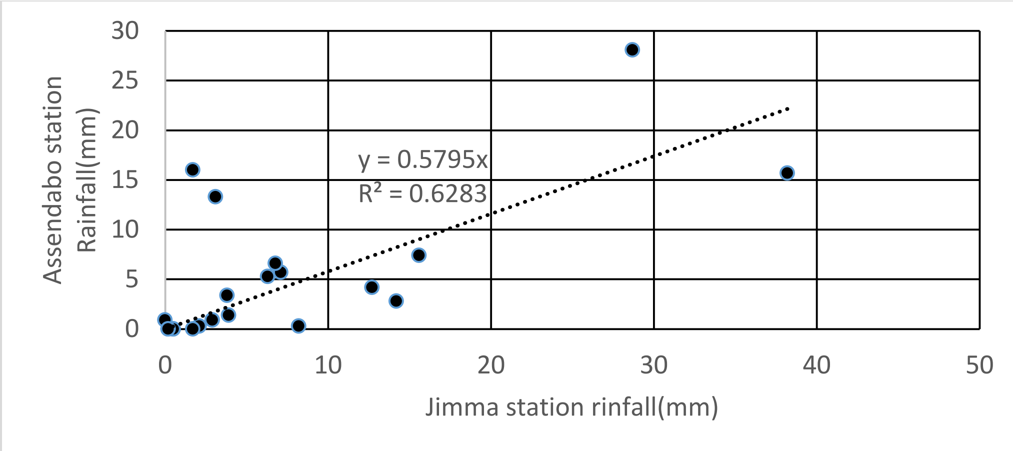


Figure 3. 7 Regression developed to estimate rainfall

Observed data in the same month of season of both stations was used to get regression line to estimate missing data.

II. Climatologically Mean of the Day (CMD)

This method uses the long-term average value of the same day of interest. It is simple a temporal average of the j_{th} day value given by:

$$Vest,i = \sum_{j=1}^{T} Vij \Big/ T \qquad 3.1$$

Where =V_i is the value of the variable for the ith day of year j,

=T is the numbers of years' data are available (Narapusetty *et al.*, 2009)

In order to fill daily data for the station of missing taking the average of the nearby station of the period of rainy season and alternatively taking long-term average value of the same day of interest for the station, data was estimated.

3.2.4 Filling Missing Observed Stream Flow Data

As described above regression analysis was used to fill the missing monthly data with satisfactory correlation coefficient (that is with R^2value greater than 0.6). The correlation was done based on neighboring station and geographical proximity and correlation coefficient shown table below.

Table 3. 2 Correlation between Gauging Station

Missed Gauging station(Y)	Nearby gauging station (X)	Correlation coefficient R2	Equation developed
Asendabo	Awaitu Kito	0.846 0.605	$Y = 18.77X^{0.628}$ $Y = 23.18X^{1.539}$
Kito	Awaitu	0.689	$Y = 0.786X^{0.285}$
Awaitu	Asendabo	0.788	$= Y = 0.083X^{0.628}$
Bidru	Asendabo	0.707	$Y = 0.191X^{0.135}$
Bulbul	Asendabo	0.878	$Y = 0.102X^{1.207}$

For example, Asendabo gauging station Adjacent Awaitu station was used in order to determine missed values for 13-Oct- 2014 using Observed data pervious and forward days in the same month of season of both stations.

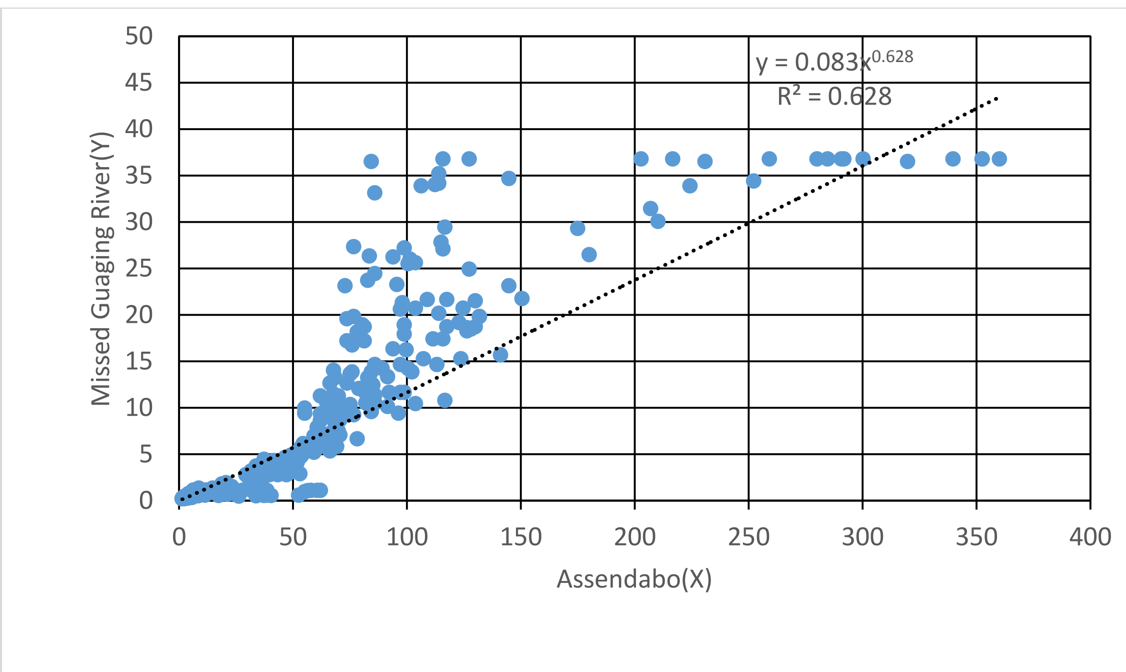


Figure 3. 8 Regression developed for stream flow estimation

3.2.5 Consistency Checking

To detect the homogeneities of data series and to check the consistency, double mass curve was plotted for all of the stations with measured precipitation, temperature and runoff. The accumulated development of a time series against the corresponding development of other times series in the same climatic region is plotted to show the double mass curve. This means accumulated values at each station is plotted against the average accumulated values of the other stations.

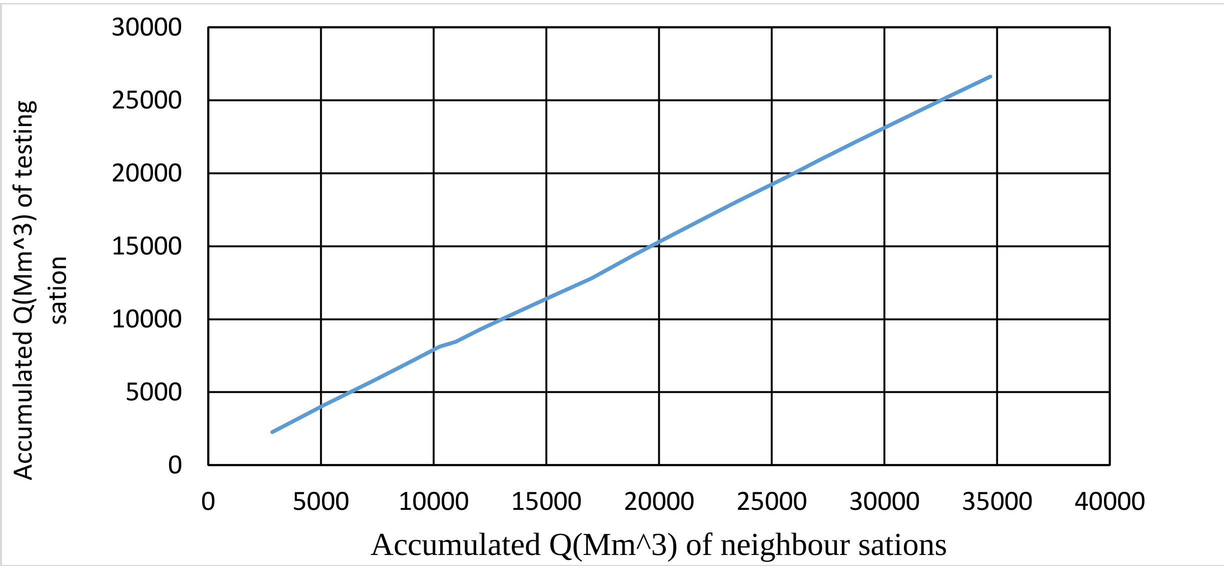


Figure 3. 9 Accumulation plot for Asendabo gauging station against neighbor station

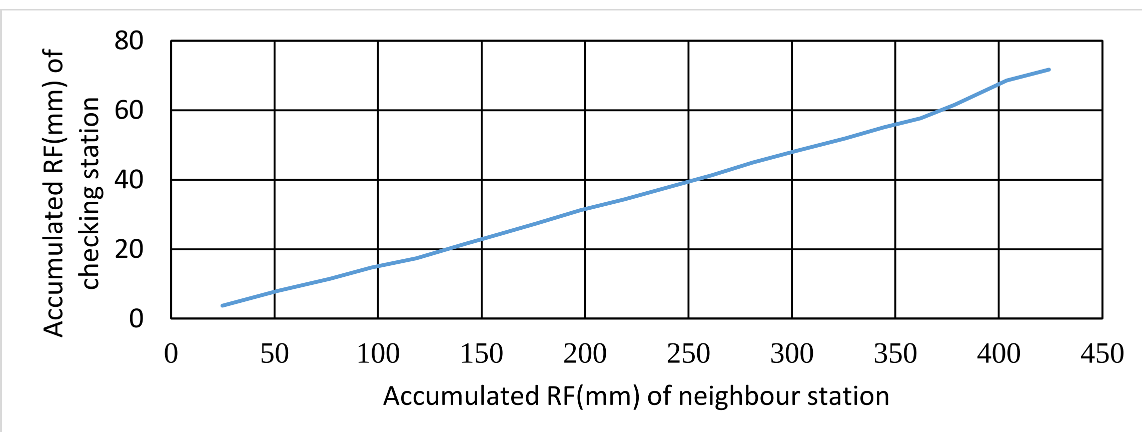


Figure 3. 10 Double mass plot of Asendabo station against neighbor stations

The graph also shows consistency of each station during the available time series. The graph shows low - high or up -down values. This happened due to some exceptional dry and wet years which come as a result of climate change. Generally, it shows consistent time series data at each station without any break or irregular pattern. See appendix-A for other station of consistency checked.

3.2.6 Areal Precipitation

The precipitation recorded at each station is point precipitation and cannot represent the whole catchment unless it is changed in to areal values. Therefore, this point precipitation should be changed in to areal precipitation. There are different methods to compute and change this point precipitation in to areal precipitation. For this research study, a method called Thiessen polygon was used. The Thiessen polygons were generated with the help of ARCGIS 10.1 tools using all the 6 selected stations in figure3.11. The areal precipitation is calculated using the following equation of Thiessen polygons method:

$$P_{Areal} = \frac{A_1P_1 + A_2P_2 + A_3P_3 + A_4P_4 + A_5P_5 + A_6P_6}{A_{Total}} \qquad 3.2$$

Where A=area, and P=Precipitation

This is the areal precipitation of the whole watershed and it is also an input data for rainfall runoff model (HBV-light).

3.2.7 Potential Evapo-Transpiration

Evapotranspiration, as a component of the soil water balance, plays an important role in the environment at global, regional and local scales.

The calculation of evapotranspiration is of major concern for regional management and irrigation scheduling, reservoir operation studies, capacity of channel design, agricultural potential studies, effects of land use, changes in water bodies, etc.

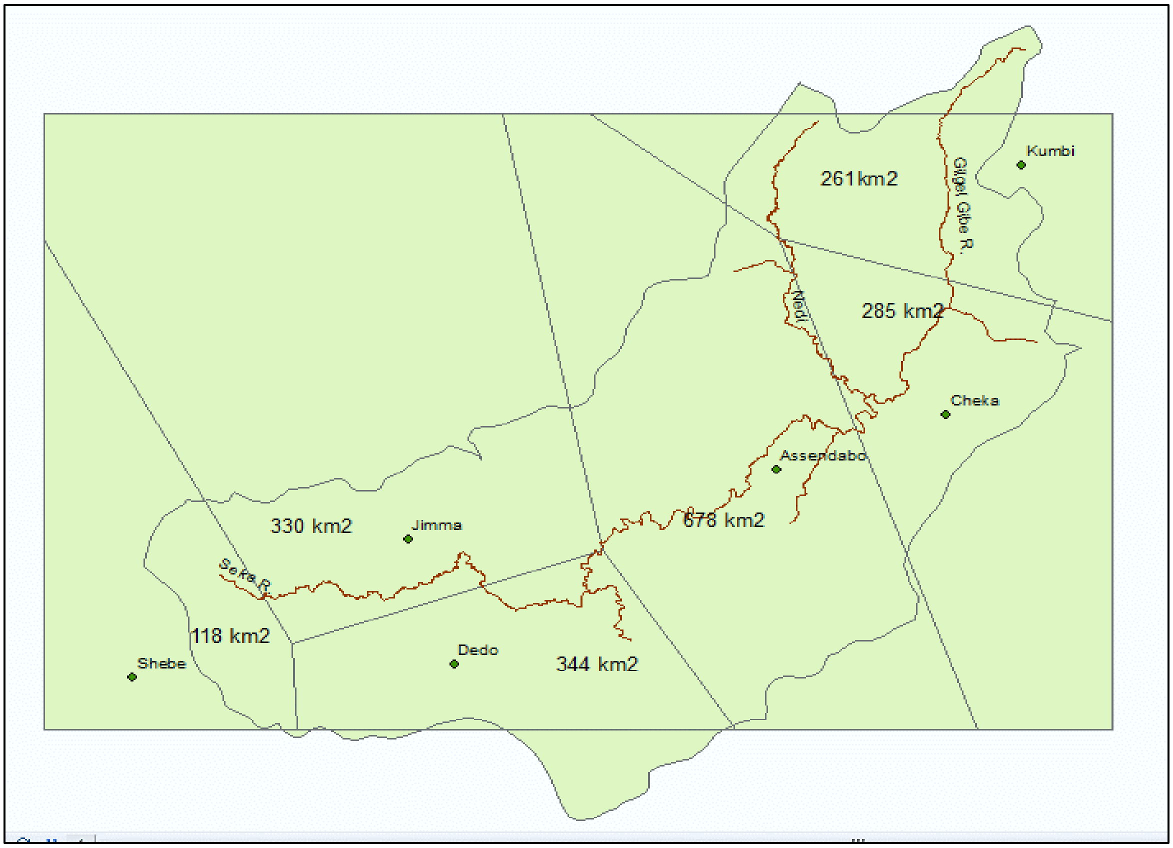


Figure 3. 11 Thiessen polygon made for selected stations

Hargreaves and Samami (1985) has been adapted to estimate potential Evapotranspiration, that uses less data input three reference weather stations (jimma,assendabo and Dedo) having better set of data are selected for the estimation of potential evapotranspiration.

$$ET_O = 0.0023(T_{mean} + 17.8)Ra\sqrt{T_{\max} - T_{\min}} \qquad 3.2$$

Where, ETo- reference Evapotranspiration (mm month-1)

Tmean - mean monthly temperature $^{(oC}$)

Tmax– mean monthly maximum temperature (^{o}C)

Tmin- means monthly minimum temperature (^{o}C)

Ra– extraterrestrial radiation (mm day-1) depending Latitude and month of the year

Ra was obtained from the table for northern hemisphere latitude of 37°and month of year tabulated below by simple interpolation

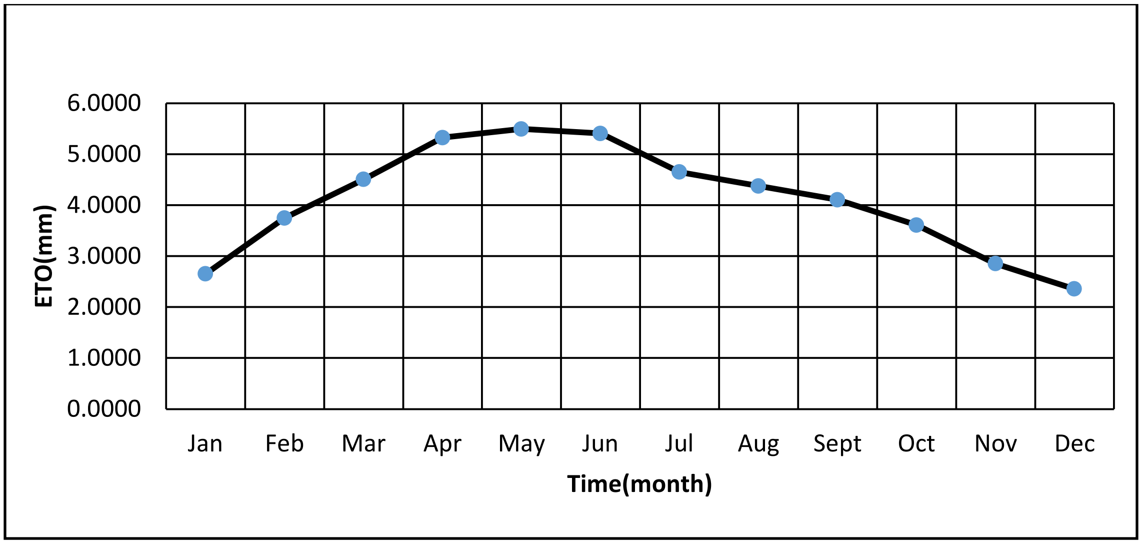


Figure 3. 12 Long term monthly evapotranspiration

3.2.8 Precipitation and Temperature Variation (PCALT and TCALT)

To account for rainfall and temperature variability with elevation in the HBV model, simple regression for long term mean annual rainy day precipitation versus elevation, and temperature versus elevation has been derived from point station data. From the long term mean values of six stations, it is found that rainfall increases on average by 5.24% per 100m (coefficient of determination is 0.78), while temperature decreases by 0.304%per 100m similarly. For modeling purposes, Jimma with 1710m.a.s.l was considered reference elevations for rainfall and temperature respectively.

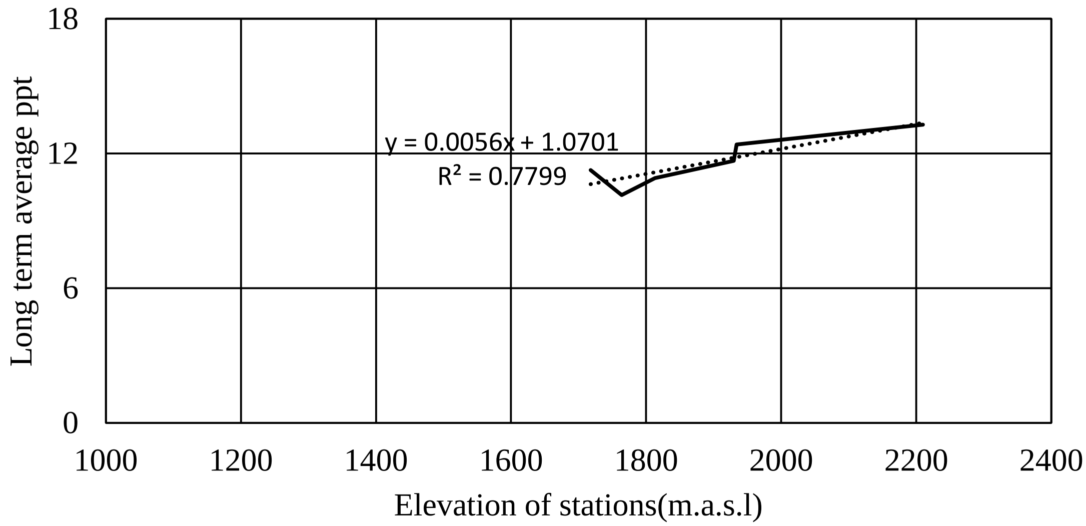


Figure 3. 13 Regression curve of precipitation versus altitude

3.3 Sensitivity and Uncertainty Analysis of HBV Model

3.3.1HBV Model

Within hydrologic model simulation, there is an unavoidable need for calibration due to parametric complexibilty of the model; best calibration of parameters is not achieved as these models are over -parameterized resulting simulation that fit the observed flow not reasonably well. This raises an issue of uncertainty within the parameterization since there are may be may acceptable parameter sets within a model that can simulate river flow for a catchment-but these come from different regions of the parameter space, an issue termed as ‘equifinality’ as reviewed.

For the rainfall-runoff modelling, a lumped version of a conceptual HBV-light model was applied. The HBV-light version requires a warm up period for the initial state variables of the model to take on appropriate values for the simulation based on meteorological conditions and parameter values. The first year (1996) of input data measurements were used for the “warming-up” of the model to estimate the initial state variables. The rest of the data were divided into two third time periods (1997-2008) calibration and one third time period (2009-2016) is used validation. The input variables to the HBV model are the daily areal of precipitation, the mean daily air temperature and the estimate of potential evapotranspiration (PET).

3.3.2 Model Calibration

Model calibration can be done by the trial–error or auto-calibration method. The trial–error method depends on plenty of trials for reducing the error of the objective. The auto-calibration method is based on stochastic or mathematical calculations and thus more widely applied in the non-linear parameter optimization. In this study model calibration together with an estimation of parametric uncertainty was carried out using the Monte Carlo optimization algorithm for the estimation of posterior parameter distributions (Touhami et al.,2013) studied the effect of different probability distributions (e.g. normal distribution and uniform distribution) of parameter values on parameter sensitivity, and found that the probability distribution can provide a clue for realizing parameter sensitivity. Although normal and uniform distributions are greatly studied in practice, other types of probability distributions were seldom investigated in previous research (Kucherenko et al.,2012.)

The Monte Carlo calibration along parametric uncertainty can be presented in the following steps:

- The sampling of the prior parameter distribution is done by MC simulations using uniform random sampling through the specified parameter ranges (Table3. 1).
- For GLUE method the model is run for each random parameter set for the basis for the rejection threshold value of 100 highest objective functional value option, the number of behavioral samples retained 1000 out of 100,000MC samples.
- The probability distributions of calibrated parameter values made by split parametric range into m bins (in to this study m = 10) of equal width, can be estimated roughly by frequency histogram.

Table 3. 1HBV Parameter Ranges

Model Routine	Meaning and unit	*LB	*UB
Soil Routine			
FC	Maximum storage in soil box(mm)	100	550
LP	Threshold in the reduction of evaporation(-)	0.3	1
BETA	Shape coefficient(-)	1	5
Response Routine			
PERC	Maximum flow from upper to lower box(mm/d)	0	4
UZL	Maximum storage in the soil upper zone(mm)	0	70
K0	Recession coeffient upper box upper outflow(1/d)	0.1	0.5
K1	Recession coeffient upper box ,lower outflow(1/d)	0.01	0.2
K2	Recession coeffient lower box (1/d)	0.00005	1
Routing Routine			

MAXBAS	Routing, length of weighting function(d)	1	5

*UB = upper band; LB= lower band

3.3.3 Model Efficiency Criteria

Model calibration and evaluation utilizes efficiency criteria as a quantitative measure of the conformability between simulated and observed variables. According to (Morias, et al. ,2007) at least one absolute error index, one dimensionless statistic and one graphical technique, such as visual comparison for a first overview on model performance, should be evaluated. The performance for all stream flow characteristics and all combinations of calibration or validation periods were evaluated using

Percentage Bias (PBIAS)

PBIAS measures the average tendency of the modeled data to be larger or smaller than the observation. It is expressed in percentage rather than the units of the constituent of interest, it allows to compare areas and seasons with widely differing values. It ranges from -100 to 100 [%], with positive values indicating model underestimation whereas negative values imply model overestimation bias (Moriasi et al., 2007). It is commonly used to quantify water balance errors.

$$PBIAS = \frac{\sum_{i=1}^{n}(Q_t^{obs} - Q_t^{sim}).100}{\sum_{i=1}^{n}(Q_t^{obs})} \qquad 3.1$$

Mean Actual Error (MAE)

Mean actual error (MAE) records in real units the overall level of agreement between observed (Q_{obs}) and simulated (Q_{sim}) flow. It is a non-negative metric which is unbounded and a perfect simulation would be zero. All deviations from the observed values are evaluated equally, so this metric is not biased towards high or low flows.

$$\mathrm{MAE}=\frac{1}{n}\sum\frac{|Qobs - Qsim|}{} \qquad 3.2$$

Coefficient of variation (CV)

To obtain a measure of spread that is relative to the magnitude of simulated discharge to observe the coefficient of variation as equation (3.4) was used:

$$CV = \frac{\sigma}{\mu} = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Qobs - Qsim\right)}^{2}}{\mu} \qquad 3.4$$

Where Q_{obs} =observed discharge, Qsim = Simulated discharge

$\mu =$Mean of simulated discharge

3.3.4 Model Validation

Once a model has been calibrated, its usefulness and reproducibility outside of the time period or calibration site it must be evaluated. Model validation seeks to assess whether the model possesses a satisfactory range of accuracy consistent within its intended objective. The best parameter set from the calibration period regarding the uncertainty analysis using GLUE is used in order to validate the model by using selected objective functions considered discussed above. It is good modeling practice to evaluate the chosen parameter sets as good representations of catchment behavior using an independent validation time period. Therefore, in order to prove validity of a model; the model should be tested against a second, independent set of stress conditions. The objective functions used to ensure model reliability applied to this study for intended objective.

3.4 Hydropower Simulation (HEC-ResiSim)

3.4.1General

The application of simulation models is one of the most efficient ways of analyzing water resources systems, which is based on physical relations accompanied by operation rules attempting to simulate a phenomena as close as possible to reality and the system behavior under a specified operation policy can be analyzed for its performance. HEC-ResSim is one of the simulation models that possess of reservoir simulators and can simulate planning and evaluation of performance of water resources system.

Reservoir operation rules can be either long term or real time. In long-term operation, a reservoir is operated with a historical long-term series of inflow. In real-time operation the released water from a reservoir in each period is a function of variables such as reservoir storage volume at the beginning of the current period or the end of pervious period, the reservoir inflow during the current period, and downstream requirement during the current period. In fact, in real-time operation the operator considers combinations of inflow volume, reservoir volume, and released water volume to make the final operation decision for the current period. The volume of released water can be a linear or nonlinear function of storage volume, inflow, or both of these variables.

By applying simulation model (HEC-ResSim), the performance of Gil Gibe -I hydropower reservoir using mean annual simulated reservoir inflow under parametric uncertainty in HBV model, selected performance indicators i.e. Reliability, Resilience and Vulnerability for existing operation and management options of historical turbine releases, reservoir performance indicators were tested and based on the result best alternative operation rule developed for the system.

Current operation policy of the Gibe-I reservoir operation was carried out using the simulated historical flow times in daily time scales. Simulation started with the initial storage, (St) taken as the average water level observed in the reservoir. With simulated reservoir inflow, (It) and turbine release or demand options, and Evaporation losses, the storage in period t is calculated as:

$$S_{t+1} = S_t + I_t - D_t - E_v \qquad 3.5$$

Where, S_{t+1} =Final storage capacity at any given period t (Mm^3),

S_t =Initial storage capacity at any given period, t (Mm^3), I_t = Daily inflow into the reservoir (Mm^3), D_t =daily demand to generate power (Mm^3), E_v =Monthly evaporation loses (Mm^3).

3.4.2 Performance Indicators Calculation

Following Simulation, in this application, reliability (R), vurneabilty (V), and resiliency (R) were calculated. Firs a constant a target demand (DF) defined for every water resources that equal to unsatisfactory value. Under these conditions, system couldn’t deliver to expected performance. Daily value of simulation times series of reservoir levels or release (Rt) for periods (N) were studied. Every water resources have a defined satisfactory range (S) and unsatisfactory (U) for related criteria (DF). If $R_t = DF$ then $R_t \in S$ and $Z_t = 1$, else $R_t \in U$ and $Z_t = 0$.

Here in this study measure reliability on the basis of whether the system meets the predefined demand criterion and if not, what percentage of the demand has been met (or not been met) over the desired period of simulation.

Reliability (Rt) computed by adopting time probability of the system to be / proportion of the time in a satisfactory state at different temporal resolution (time based reliability ((Hashimoto et al. 1982).

$$R_t = \sum_{t=1}^{Nt_{ot}} Z(t) \Big/ N_{tot} \qquad 3.6$$

Resilience (Res) computed by adopting ratio of the minimum release for constant target demand DF and a minimum release R constant for each failure event) (McMahon et al.2006).

$$\mathrm{Re}\, s = R_{\min} \Big/ DF \qquad 3.7$$

Vulnerability (V) computed by applying Mean of NF cumulative deficits (Kjeldsen and Rosbjerg, 2004)

$$Vur = mean(D(i), i = 1, ...NF) \qquad 3.8$$

Reliability and resilience are both positive measures (higher, the better). Vulnerability, Vulnerability is a measure of the extent of failure which here has been shown as the average shortfall among all the continuous failure or unsatisfactory.

3.4.3 Input data

Efficient management of hydropower reservoir can only be realized when there is sufficient understanding of interactions existing between reservoir variables and energy generation. Reservoir inflow, storage, reservoir elevation, turbine release, net generating head, plant use coefficient, tail race level and evaporation losses, leakage and seepage losses are the major hydropower reservoir variables affecting the energy generation. Therefore, this section presents all the input information used in the simulation.

I. Gibe-I Dam Physical (reservoir) data

At most reservoir flow requirements and constraints vary depending on the state of the reservoir pool. That is, the rules change depending on the amount of water stored in the reservoir.HEC-ResSim describes this dependency by dividing the pool into elevation bands, called zones, and applying a different set of prioritized rules to each operating zone in the reservoir. An operating zone is described by a water elevation curve representing the top of the zone. When the water level in the pool exceeds the top (or bottom) of a zone, its rules no longer apply to release decisions. The top-of-zone elevation curve can be a constant or can vary seasonally. A reservoir in HEC-ResSim must have a target elevation. A reservoir's target elevation, represented as a function of time, is called its Guide Curve. It is the dividing line between then upper zones of the reservoir (typically called the flood-control pool) and the lower zones (typically called the conservation pool).

Table 3. 3 Gibe- I hydropower reservoir design parameter

Parameter	Value
Maximum water level	1673m .a.m.s.l
Normal water level	1671m a.m.s.l.
Minimum operating level	1653 m a.m.s.l.
Total storage at maximum water level	668Mm^3
Storage of reservoir at flood control level	839Mm^3
Dead storage	171Mm^3
Spillway capacity	2253m^3/s
Rated power	3x70MW
Rated design head	223.4m
Rated design discharge	3x33.91m^3/s
Designed power plant factor	0.8
Average load factor	0.46
Total maximum output	184MW
Average energy annual	722GWH
Tail water level	1430m.a.m.s.l

Source: EEPCO (2004)

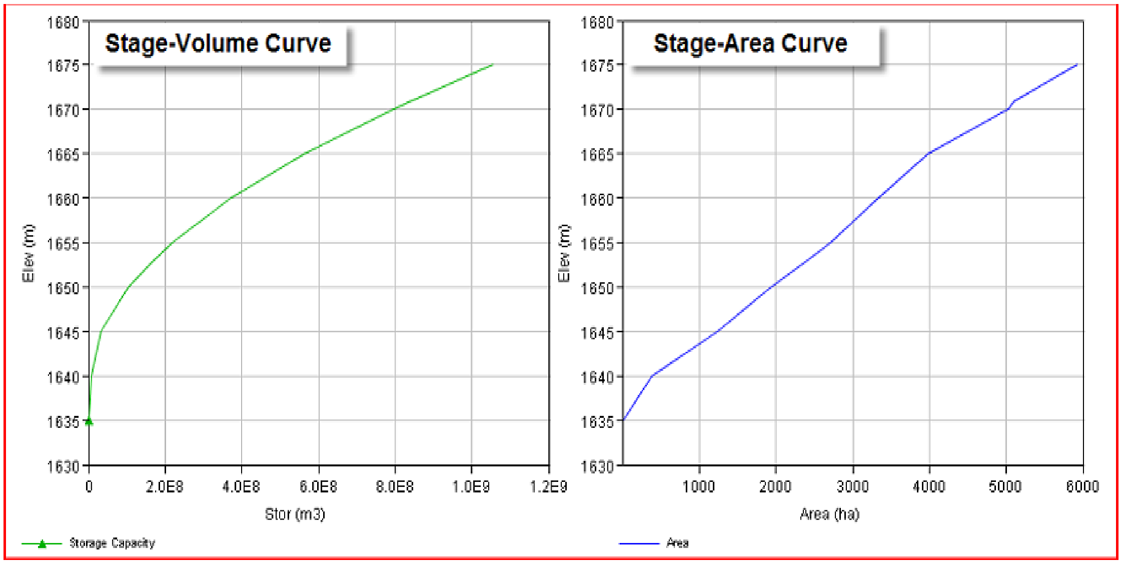


Figure 3. 14 Stage-Volume and Stage-Area Curves at Gibe- I reservoir

II. Reservoir inflows time series

Reservoir time series inflow was mean, standard deviation and observed flow out of the simulated stream flow under parametric uncertainty in HBV model. These daily simulated time series inflows (1996-2016) were used as reservoir inflow:

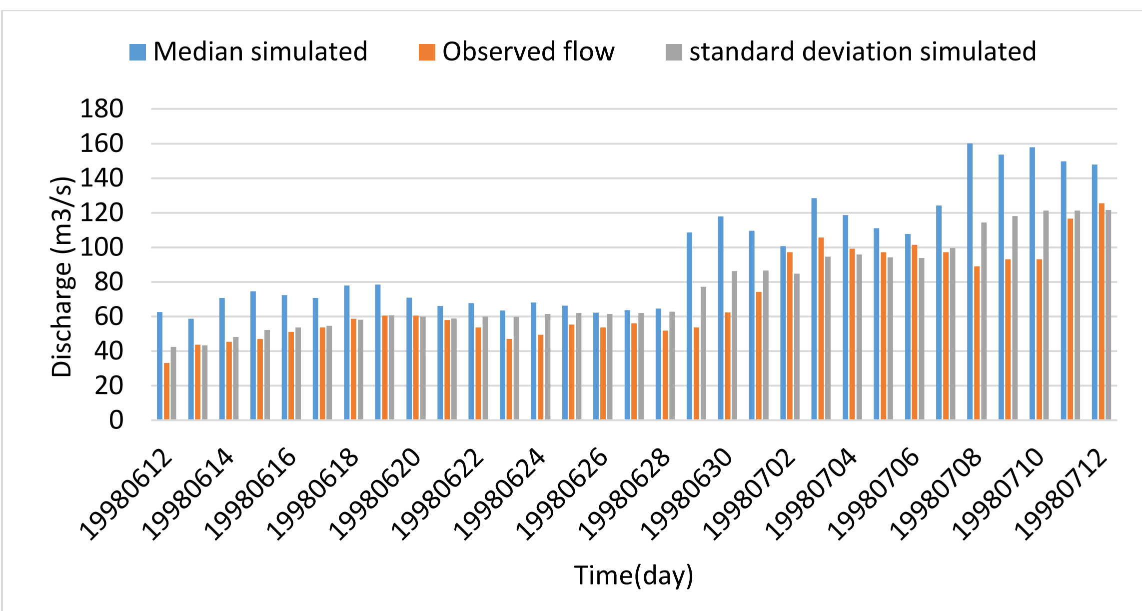


Figure 3. 15 Simulated inflow of reservoir

III. Environmental demand

To maintain acceptable environmental conditions downstream, the river should be maintained at a minimum flow. Ecological flow is water released for the purpose of healthy natural ecosystem. This release is considered during the planning of any reservoir system. If this is not considered, then it has significant effects on the impoundment of free-flowing river habitat, blockage of fish migration, and reduced water quality in reservoirs and downstream river reaches (EEPCO, 2006).

Table 3. 4 Minimum environmental flow release from Gibe- I reservoir in m3/s

Month	Jan	Feb	Mar	Apr	May	Jul	Aug	Sep	Oct	Nov	Dec
Gilgel Gibe I and II	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

IV. Evaporation

The water stored behind the dam will be partly lost due to evaporation. This leads to a decrease in available water resources and makes reservoir water users. In this research study, evaporation data were taken from hydrology documentation report of the project in table 3.5.

Table 3. 5Monthly evaporation from Gibe-I reservoir

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
evaporation (Mm^3)	30.2	27.9	25.8	23.5	21.3	20	21.9	26.7	32.8	34	33.6	32.19

V. Seepage and Leakage

Seepage is the slow escape of a liquid through porous material from a dam. All earth dams have seepage due to water movement through the dam and its foundation, however, the rate of seepage must be controlled. For effective water resources management of reservoirs/dams/or small ponds, seepage calculation and estimation has become crucial as it affects the stability of any reservoir.

Gibe- I Reservoir is prone to losses through seepage and leakage at foundation and body of the embankment as observed in inspection gallery drain hole and piezometers. However only two years recorded seepage and leakage in monthly level from six functional drain galleries and piezometers were exist from Gilgel Gibe I operation and maintenance staff library. Therefore, due to short period of recorded and some missed data it was unreliable and neglected.

VI. Release decision

Each reservoir operating goal is described by a flexibly-defined rule that, when evaluated, specifies a minimum or maximum limit on the release from the reservoir or outlet. The rules are placed in a prioritized list in one or more reservoir zones. As each rule is evaluated, its calculated minimum and/or maximum flow is applied to an evolving “allowable range of release”. At the start of the release decision process, HEC-ResSim sets the allowable release range to the physical limits of the dam or outlet: the maximum of the range is the total maximum capacity of the outlets for the current pool elevation, the minimum of the range is the minimum release capacity of the outlets, usually zero. As a rule is applied, it may narrow the allowable release range. If a rule does not either raise the minimum allowable release or lower the maximum, then that rule will have no effect on the range. Once all rules have been evaluated and applied to the range, the allowable range is considered complete and the “desired guide curve release” is computed. The desired guide curve release is the release the reservoir would make if it were not constrained by any “limits”. The final release is the closest value to the desired guide curve release that falls inside the allowable range and maximize the output of the desired objective.

For a given target power installed, release is a function of available water and head. If the available water is less than none of the turbine release, no turbine is to be operated which means the power production is zero. If the available water is between the beyond full reservoir capacity and the minimum operating level either or all of the turbines are to be operated at certain percentage of rated discharge. If the available water is beyond full reservoir capacity, all turbines are to be operated at maximum capacity i.e. 100%. This indicates that the percentage of water that is available for release each day from the operation is subjective construct defined by managers and operators. Therefore, this examines performance of reservoir for planned historical turbine release options.

3.4.4 Model Setup, Watershed Set up and Reservoir Module

I. Model set up

Any reservoir and water balance simulations mainly start with identifying the major inflow and outflow components. Figure 3.16 below shows the major components that need to be defined in any reservoir simulation analysis. Usually inflow consists of runoff that drains into the reservoir, but can also have a component of recharge from ground water source. On the other hand, outflow can be made of several components including power plant release, environmental release, net evaporation, spillway release and seepage.

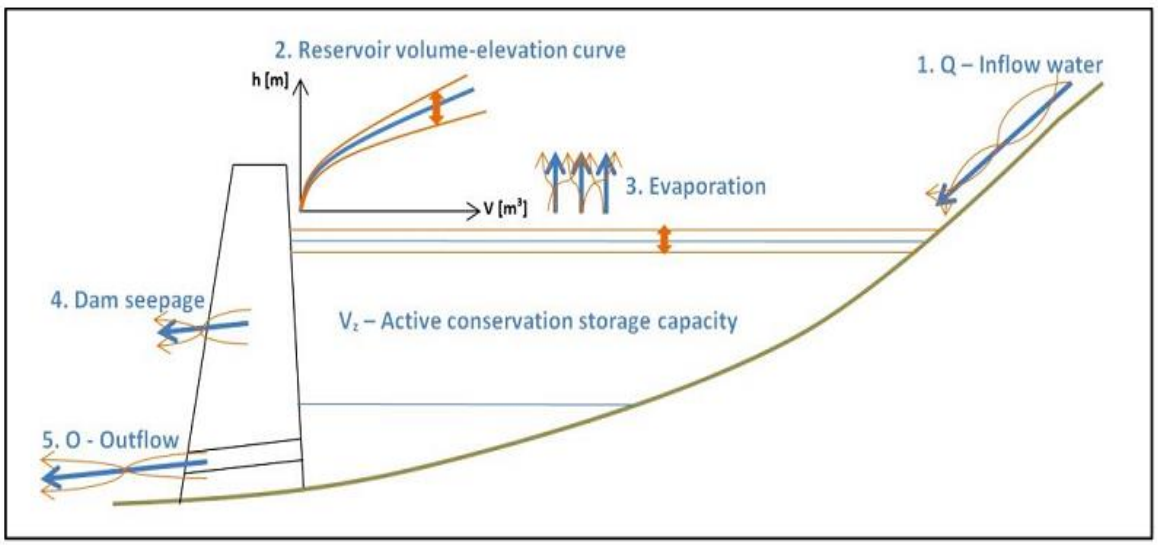


Figure 3. 16 Inflow and outflow components to embankment dam

The applied software can simulate the reservoir inflow and outflow given the required information on dam characteristics, spillway outflow characteristics and power demand. The program is organized in to three modules namely watershed setup, reservoir network and simulation. The watershed setup module helps the simulator to define the various elements of the river system including the streamlines, the dams and the diversion structures. The reservoir network module is where the reaches are defined and the physical characteristics related to the dam, its reservoir and the outlet works are inputted. The simulation module performs the simulation using inputs defined in the watershed setup and the reservoir network. The various input data fed to the system are listed in the following section.

I. Water Shed setup the watershed setup is where every component of the model is defined. Here the simulator defines the streamlines, the reservoir, the diversion works along with their relative positions and arrangements. Figure 3.17 shows the model setup in the watershed module.

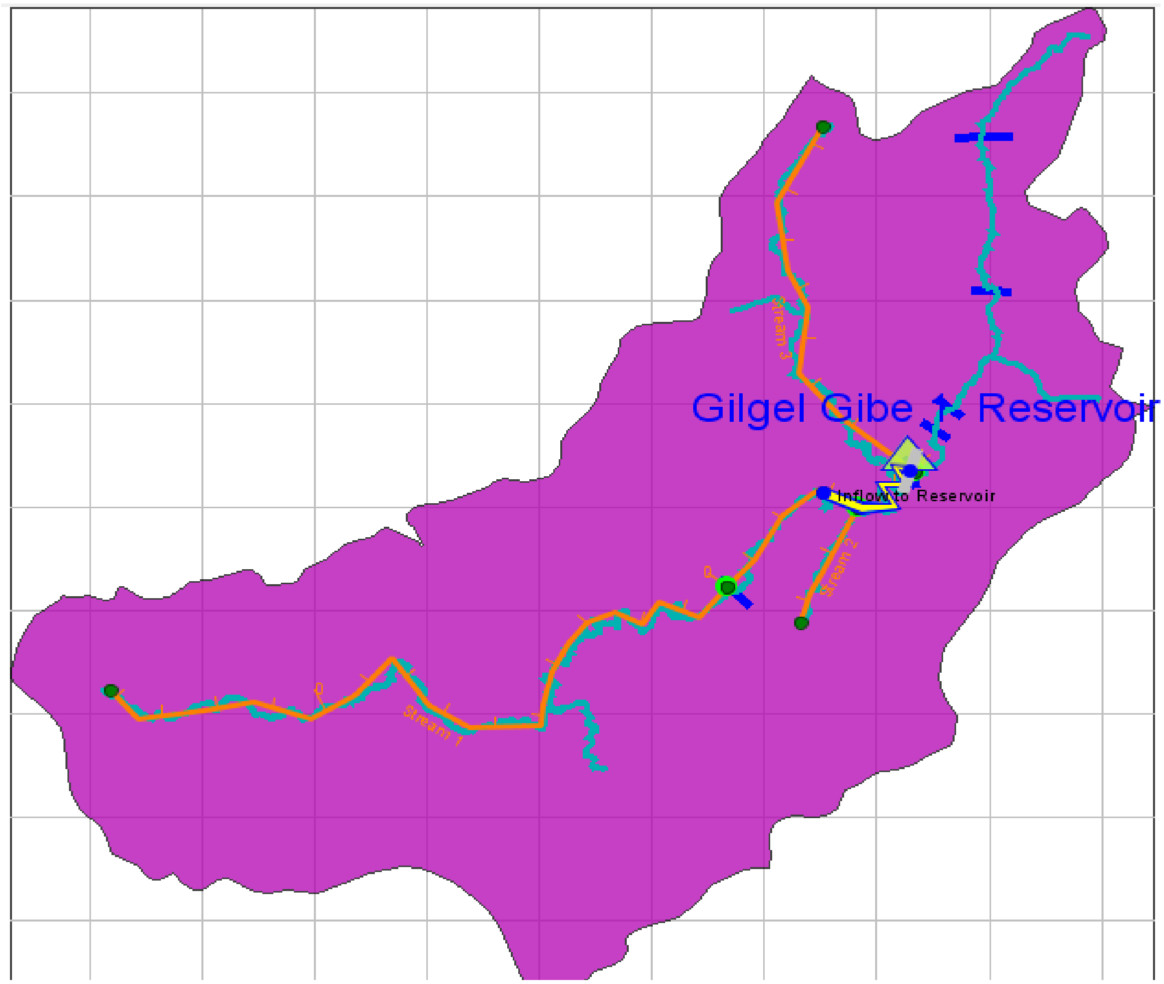


Figure 3. 17 Gibe-I watershed setup

This has been done in as a first step taking in to account the major components associated with the dam. In watershed setup, the arrangement river does not need to be geo-referenced neither it exacts shape be drawn. The software only requires the physical information pertaining to each component (the dam, reservoir, spillway, outlet works etc…) be defined. That is the only way the system recognizes the components.

II. Reservoir setup

This module mainly deals with defining the physical parameters associated with the various elements of the hydropower system defined in the watershed setup. A typical interface for feeding in these parameters is shown in figure3.18. The interface lets the user define various elements associated with the reservoir and the dam. In this simulation, elements like evaporation, power plant release and spillway release are defined.

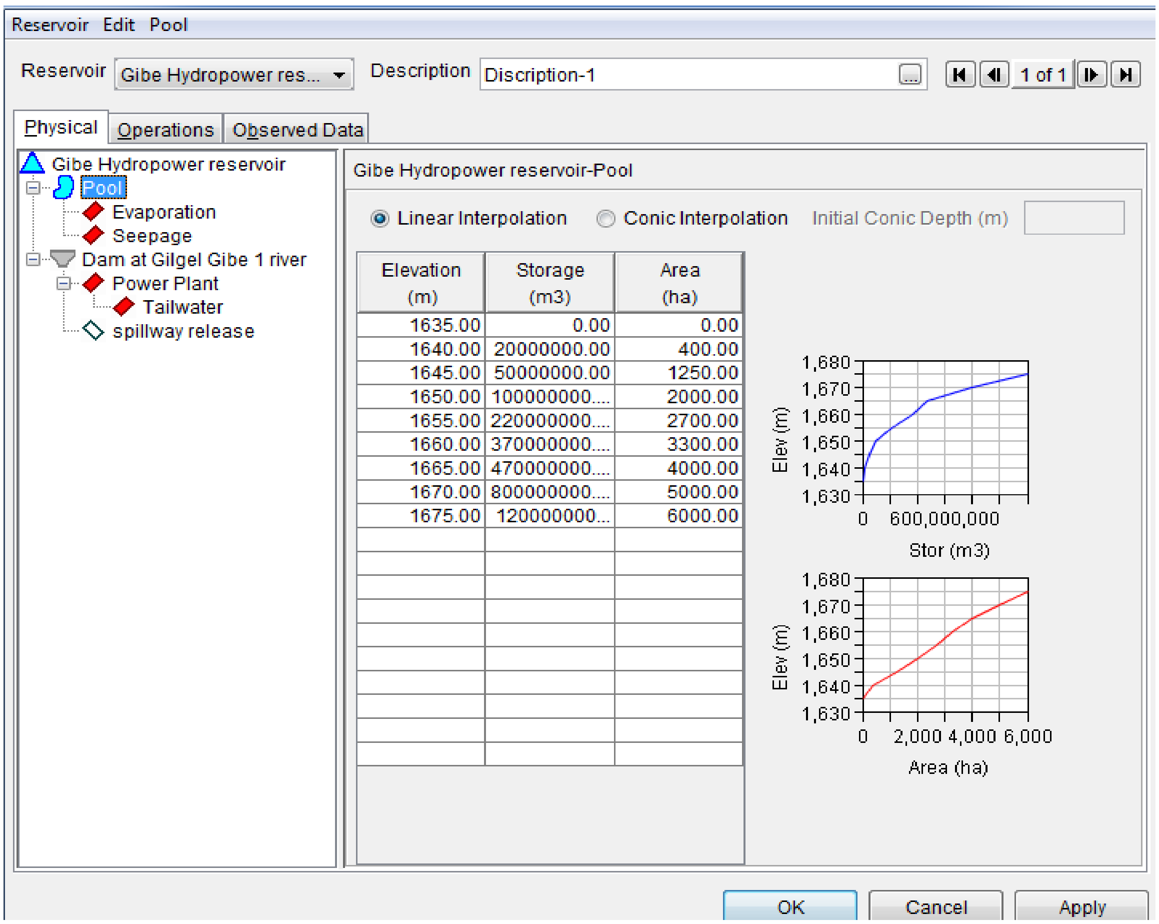


Figure 3. 18 Gibe-I Reservoir module interface

The next procedure in the reservoir setup is defining the various regions of the reservoir namely the dead storage, the conservation and the flood zones. These zones are shown in a simple schematic drawing below in figure 3.19.

Dead storage*:* is part of the reservoir from which water cannot be accessed by the outlet works. This region is assumed to be entirely filled with sediment in the design life of the dam (1640-1653m.a.s.l.)

Operation zone: is part of the dam from which water is used for the intended purpose of power generation. This zone extends from the top of the dead storage to the crest of the spillway (1653-1671.2m.a.s.l).

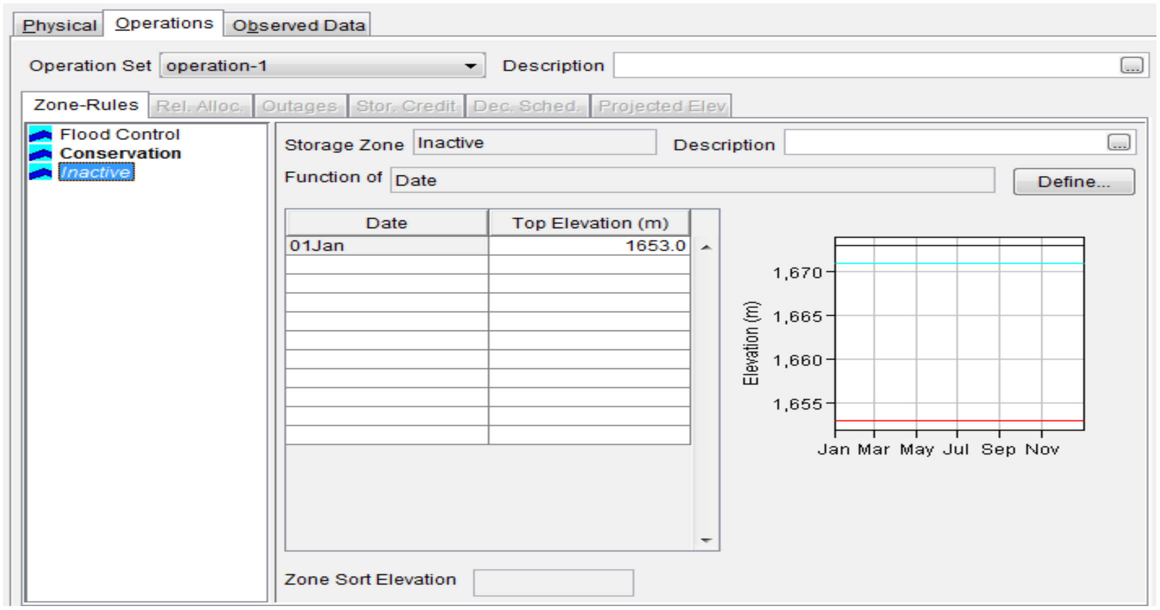


Figure 3. 19 Operation zone interface

Flood zone: represents the region of the dam above the spillway crest in case of uncontrolled spillways. In gated spillways, the flood zone usually starts at the top of the gate, above which the water can no more be controlled (1671.2-1673m.a.s.l).

In addition to this, the user needs to establish various alternatives that mainly describe the initial boundary conditions.

III. Simulation module

The final of the three modules is the setup module. As the name clearly indicates, here simulation runs are made after look back, model start and end dates are established. The results of the runs are presented both in tabular or graphical ways. These are shown in the result section.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Sensitivity and Uncertainty Analysis of HBV Model

4.1.2 Probability Characteristics of Calibrated HBV Parameter Values

The posterior distributions of the parameters are defined the likelihood values. The shape of the posterior density depends on the catchment and on the parameter. In each case the posteriors of model parameters were examined. As shown in figure 4.1a and b of some of the HBV parameters in Gibe –I basin follow a normal distribution, whilst some other evaluated parameters were normal distributions.

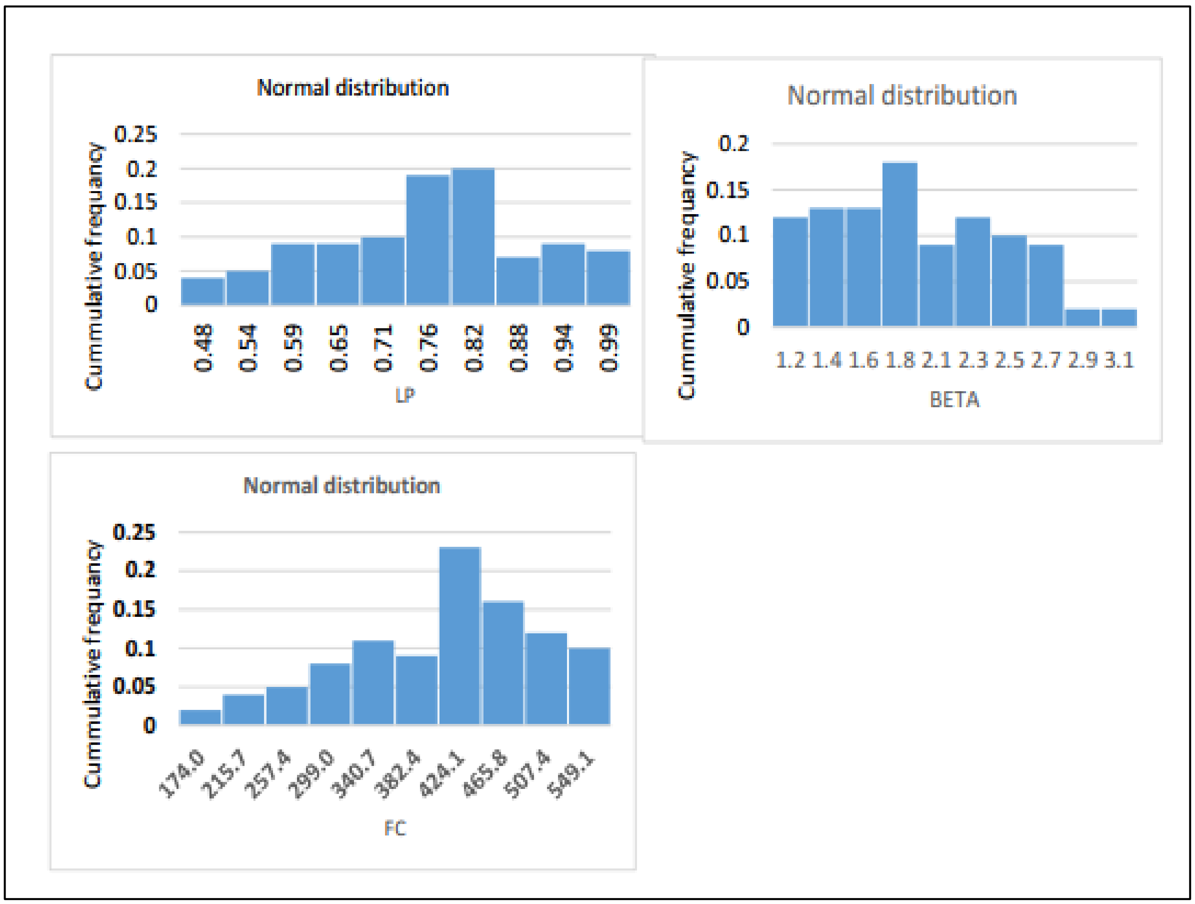


Figure 4. 11a Histograms of the estimated posteriors for selected parameters

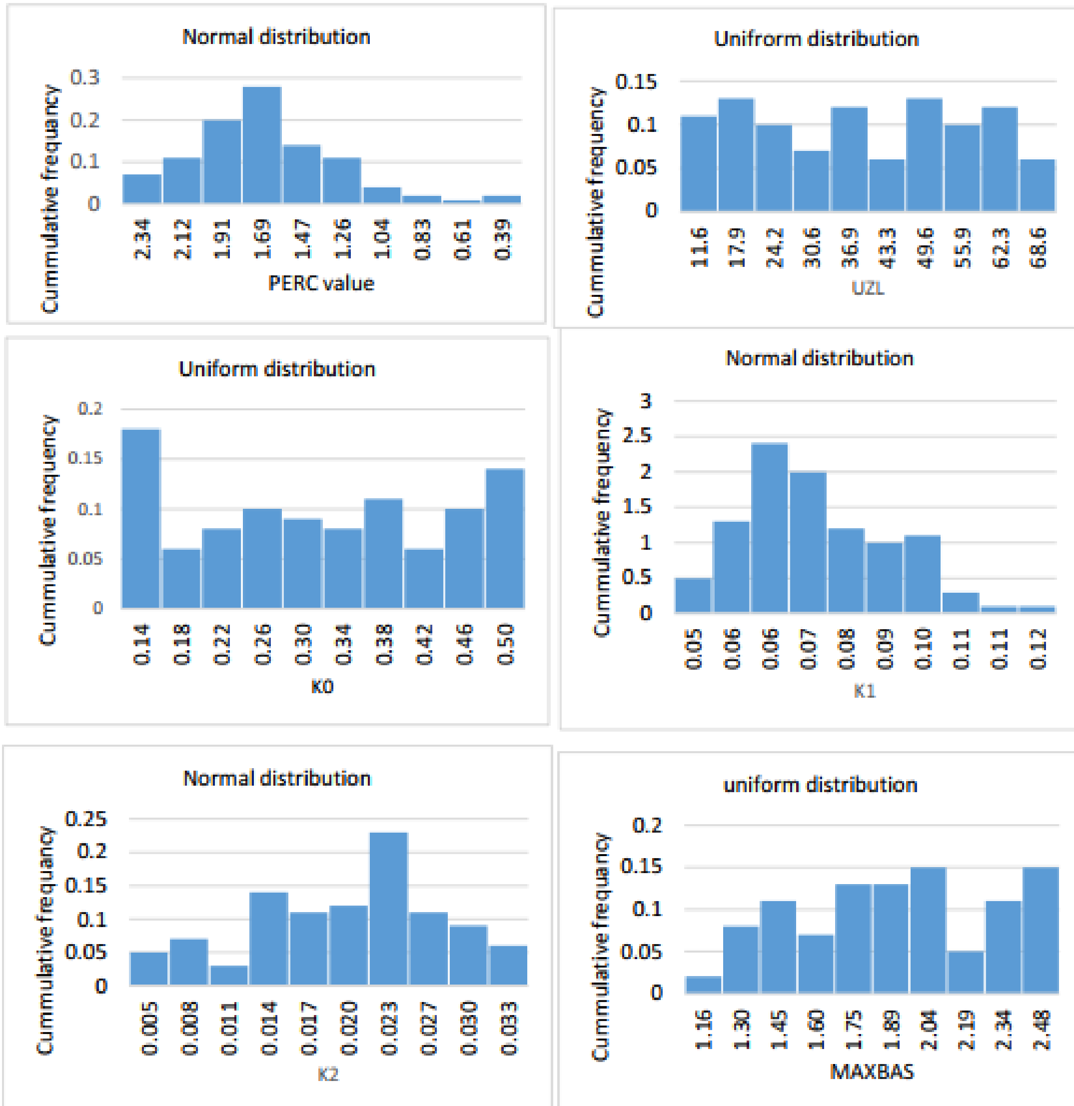


Figure 4. 21b Histograms of the estimated posteriors for selected parameters

The shapes of the distributions indicate the degree of uncertainty of the estimates. The normal distribution with sharp and peaked distributions is associated with well identifiable parameters. Figures 4.1a and 4.1b, LP, FC, PERC, K_2, K1 and BETA are relatively well identified parameters. While uniform distribution with flat and/or spread distributions indicate more uncertain parameters. Figure 4.1and 4.1b uniform distribution, MAXBAS, K0, and UZL are less identified parameters.

Furthermore, sensitivity to single parameters is evaluated based on the cumulative distribution of the frequency of parameters with in each bin. A steep gradient in the distribution function indicates high sensitivity and suggests that parameters are well identifiable. The results of the model calibration using the Monte Carlo optimization, the median and standard deviation of the posterior distribution are presented in Table 4.1. The optimum parameter values vary between catchments as well as median and standard deviation of the posteriors distributions. It is also notable that the mean and median values of all parameters distributed to center to outward of the parameter ranges as shown table of two measures (mean and standard deviation) describing posterior distributions for the parameters

Table 4. 1 the model calibration results

Parameter	PERC	UZL	BETA	K_0	K_1	K_2	FC	LP	MAXBAS
Mean	1.8	40.1	1.95	0.32	0.07	0.021	445	0.79	2.1
standard of deviation	0.75	18.2	2.05	0.11	0.02	0.017	146	0.69	0.508

The presence of extreme values or outliers is easily detected in a graphical display of the data. (Wilcox ,2009) has indicated the importance of box plot in assessing the existence of outliers. Hence, the presences of outliers for the discharge simulated for median standard deviation (minimum) and observed of the parameters using box plot shown figure 4.2.

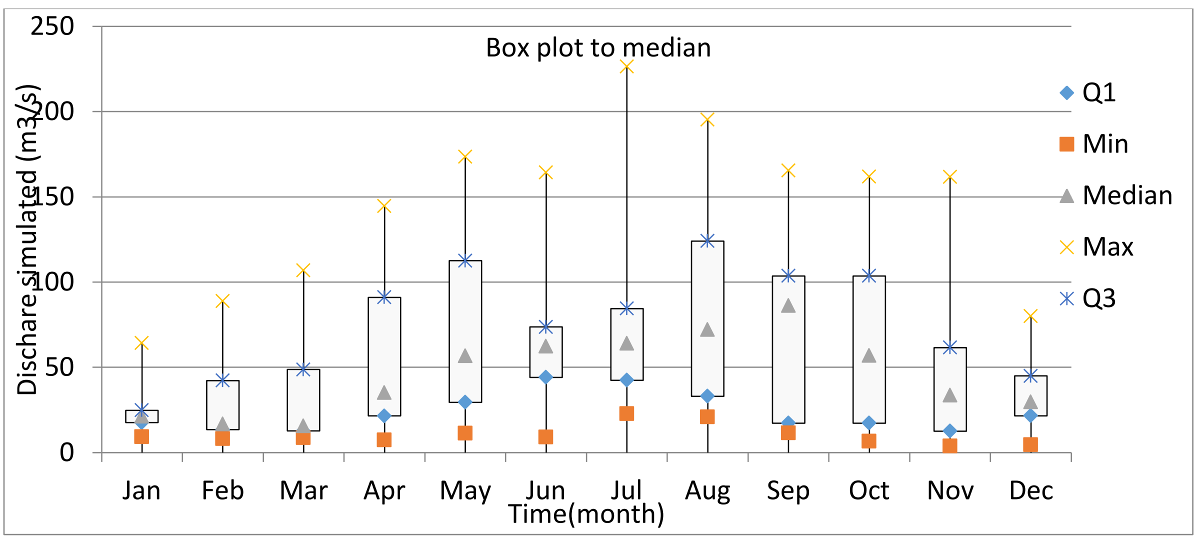


Figure 4. 3Box plot of spread of simulated runoff to median parameter

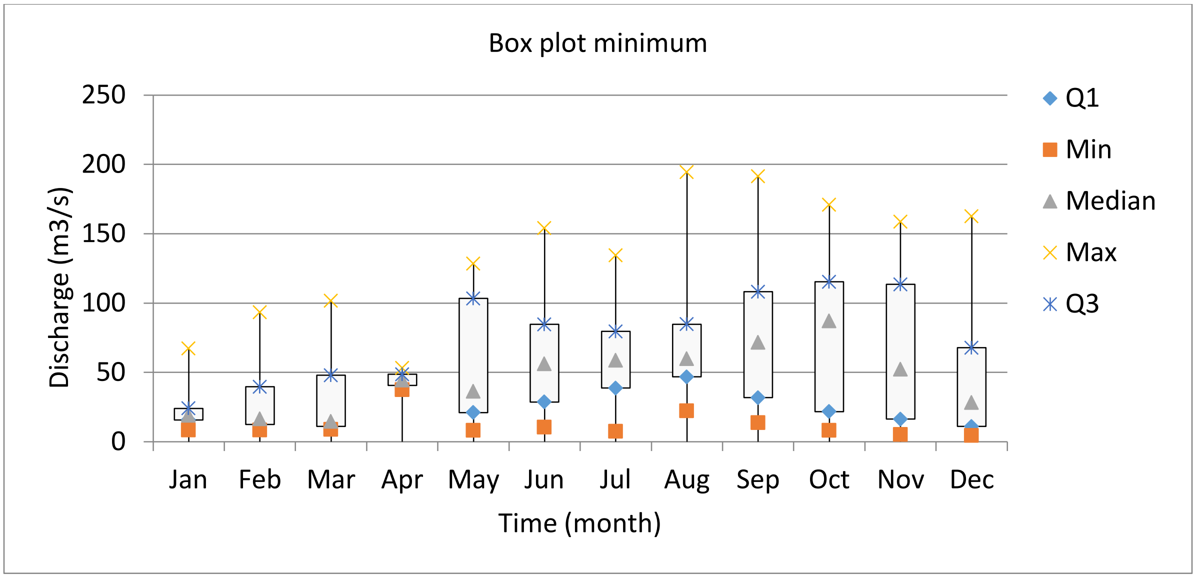


Figure 4.4 Box plot of spread of simulated runoff to minimum parameter

4.1.3 Model performance Indicators

The model efficiencies that could be achieved for different period is shown table 4.2

Table 4. 2 Model performance indicators

	Parameter set	Model efficiency		
		Reff	LogReff	Mean difference
Calibration	mean	0.7	0.76	-24mm/year
	standard deviation	0.63	0.67	17mm/year
Validation	mean	0.67	0.61	33mm/year
	standard deviation	0.62	0.58	41mm/year

The model is better in the simulating at median parameter than standard deviation of the parameter. In both cases the parameter value is less likely transferred to different period with in the basin. This may be due to data quality and any other error; it is consistent during different period. These results suggest in both cases indicate that the model better simulates low flow than higher flow.

In addition to this, some indicators were evaluated to different periods with in parametric ranges i.e. median and standard deviation. The model is better when evaluating by percentage of bias, absolute relative error and coeffient of variation for parametric setting and at different periods. The result of stastical parameters shown in Table4.3

Table 4. 3 Stastical model evaluation parameters

	Stastical indicators	Percentage bias (PBIAS)	Absolute relative error(MAE)	Coefficient of Variation (CV)
Calibration	mean of parameter	-1.14%	11.4	0.015
	standard deviation	2.14%	6.7	0.023
Validation	mean of parameter	23%	17.2	0.092
	standard deviation	21.5%	14	0.087

4.2 Hydropower Performance Simulation

The simulation result when two turbine units are continuously operating shown in figure 4.5for simulated runoff for minimum parameter values. Water level becomes deeper and wider to the bottom of conservation pool level which indicates that it has relatedly moderate. Speed of refilling or returning to its original position. The simulated figure 4.6 result when simulation observed flow indicates that dam has high speed of recovery for refill and the storage reaches never minimum level of the pool. The graph is less undulating

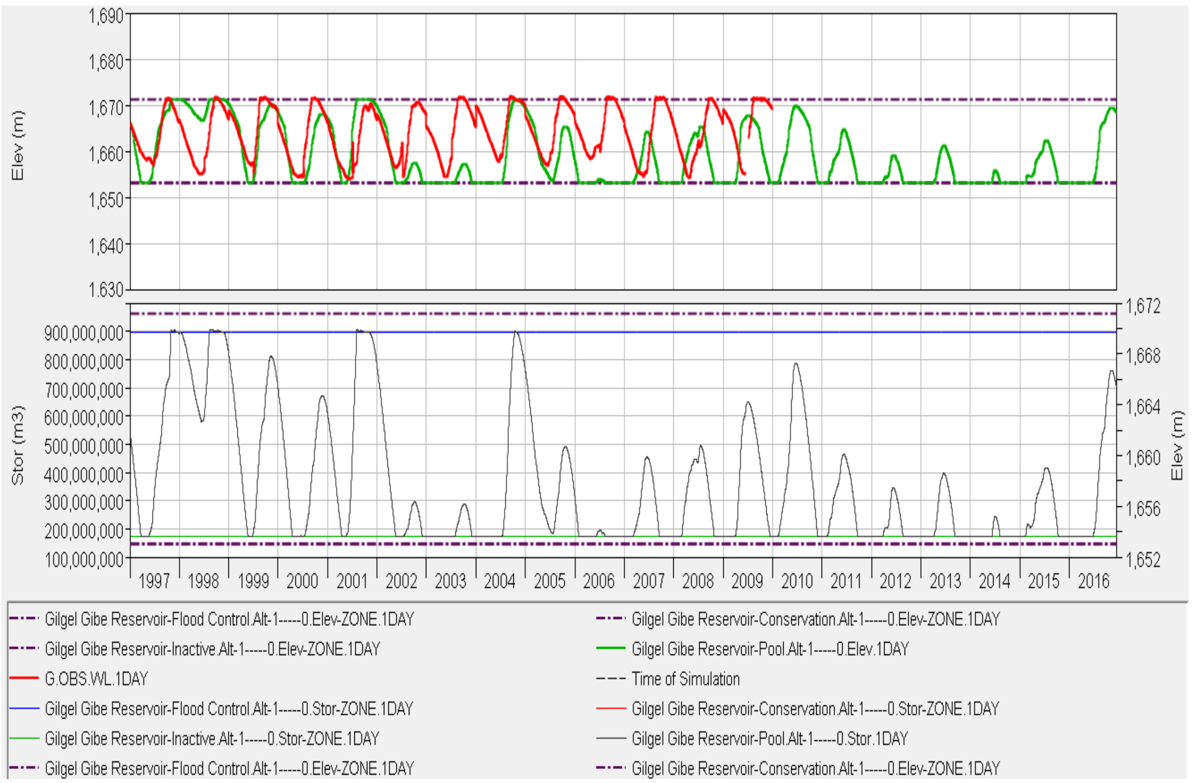


Figure 4.5 Operation simulations to two turbines to minimum parameter simulation

and deeper and narrower at the refill period for its power release. Simulated reservoir water better fitted with recorded reservoir water level of some years and reservoir inflow –outflow for mean flow simulation. In some region of the water level recorded it is unfit with simulated water level. This is may be due to unload condition of the system because it is observed that the observed graph is above the simulated due to less loading on the system.

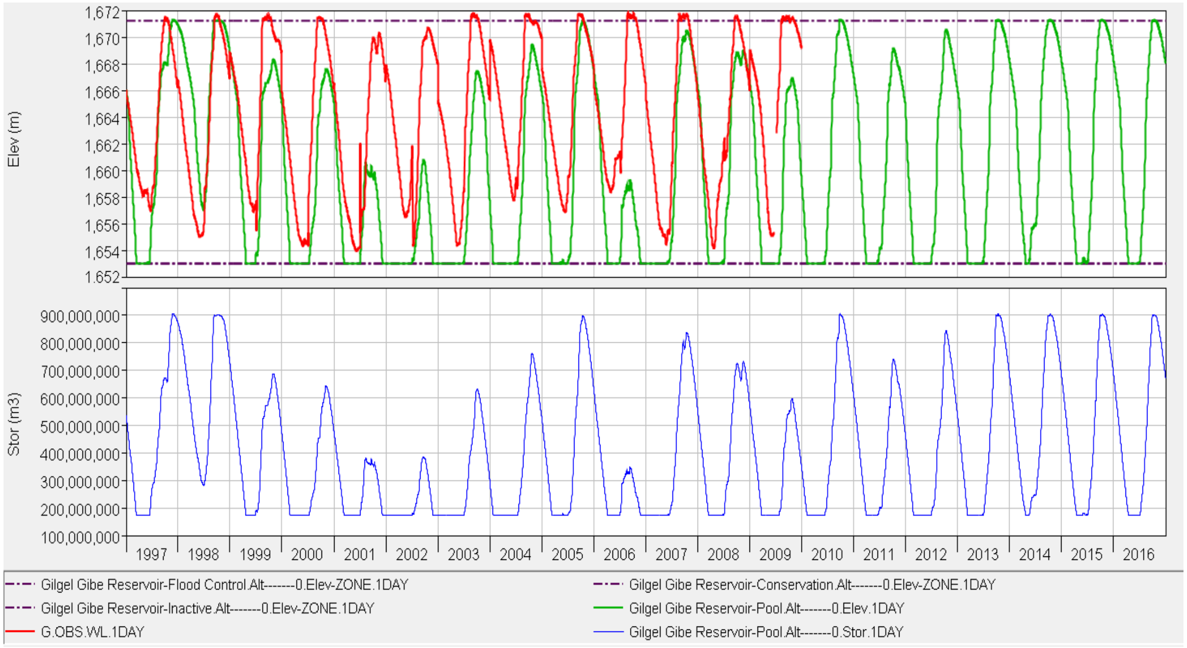


Figure 4. 5 Operation simulation to two turbines to observed flow simulation

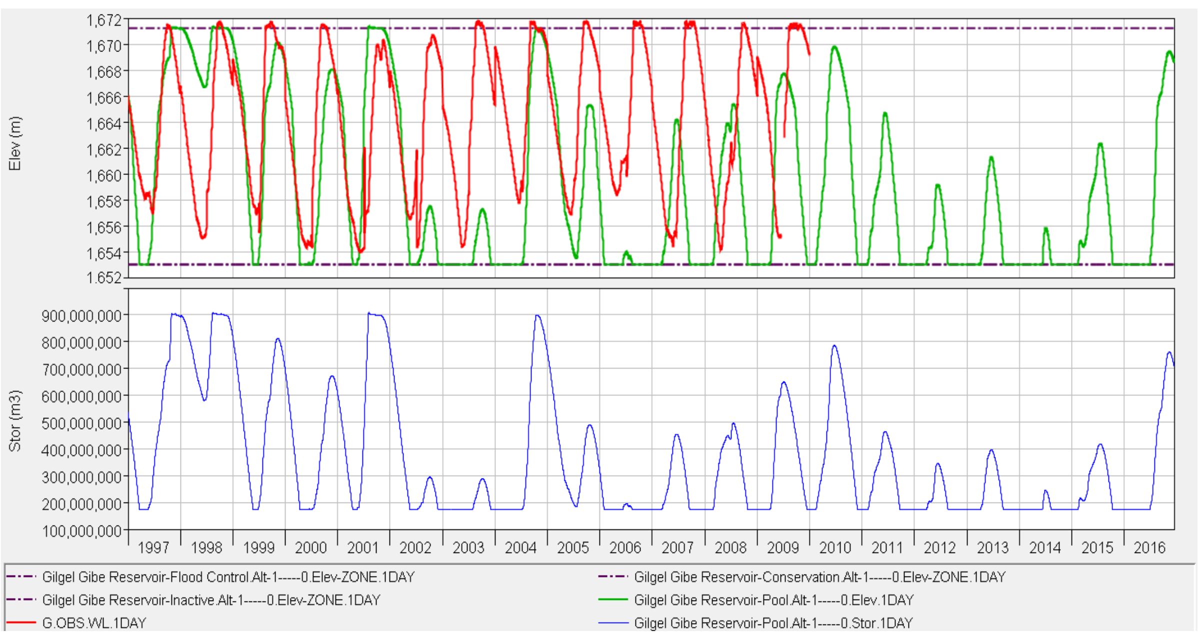


Figure 4. 6Operation simulations to two turbines for median flow simulation

Simulation when three units' result indicates that dam has less speed of recovery from the unsatisfactory as the storage reaches near in active zone of reservoir in a month of april-May.The graph is more undulating, deeper and wider at the unmet release power release.

Table 4.4 Result of Performance Parameter

Indicators	Inflow alternative	Demand Alternative	
		Two units	Three units
Reliability	Median	0.965	0.67
	Minimum	0.87	0.56
	Observed	0.94	0.61
Resilience	Observed	0.95	0.59
	Minimum	0.87	0.56
	Median	0.93	0.57
Vurneabilty	Median	2.4Mm^3	3.9Mm^3
	Minimum	3Mm^3	4.8Mm^3
	Observed	2.71Mm^3	3.6Mm^3

Reliability

The reliability result of the simulation suggests that the Gibe -I hydropower reservoir while operating at maximum designed power release capacity, it is reliability to meet power release of 0.67,0.56 and 0.61 to median, minimum and observed reservoir to total power demand to produce 180MW respectively. When the system is operating two turbine release capacity, its reliability of 0.965, 0.87 and 0.94 to median minimum and observed inflow respectively. At this operation condition, the system vulnerable to excess spills for all condition shown in table 4.5.

Resilience

The results of Resilience for different number of units at the Gibe- I dam indicates that the duration spent by the system in an unsatisfactory state when continuous operation at the maximum release power capacity is three inflow condition is low and this suggest that it takes longer time to recovery or refill after failure to meet required power demand.

On the other hand, while production using to two turbines its resilience of 96% or high speed of recovery to refill to median inflow case.

Vulnerability

The result of maximum amount of Vulnerability for simulated time period at daily time for maximum release capacity, the deficit release is 4. 8Mm^3 to minimum flow alternative. This result suggests that the system is unable to meet the required power release and there is high amount of unmet demand. The system is capable to meet the power release one and two turbine operation at full capacity, average vurneabilty of 4.2Mm^3 deficit release.

Generally, the system is found to be less reliable, spends more time to recover and more vulnerable when used with three units but it shows an improved reliability, with a good recovery time and less vulnerable when used with two units and three units alternatively based real time guide curve operation. The increase in the reliability will increase the resilience and make the system less vulnerable. Within this operation, average plant factor 0.61 compared existing operation plant factor 0.46. This indicates that the system performs to unit's operation alternative to median average inflow simulated.

Table 4.4 Parameters of reservoir operation and hydroelectric power generation during the simulation Period

Alternatives	Average	Maximum	Minimum
Two units to observed inflow			
Power Generated (MW)	59.76	60.01	58.27
Plant Factor	0.32	0.33	0.32
Elevation (m)	1670.51	1671.43	1665.03
Two units to mean flow			
Elevation (m)	1664.63	1671.4	1653
Power Generated (MW)	112.91	121.85	4.81
Plant Factor	0.61	0.66	0.03
Two units to minimum flow			
Elevation (m)	1658.58	1671.36	1653
Power Generated (MW)	127.93	183.86	3.32
Plant Factor	0.7	1	0.02
Three units to observed flow			
Elevation (m)	1662.49	1671.39	1653
Power Generated (MW)	120.09	139.31	3.32
Plant Factor	0.65	0.76	0.02
Three units to mean flow			
Elevation (m)	1655	1671.25	1653
Power Generated (MW)	63.49	146.65	
Plant Factor	0.35	0.8	0

Three units to minimum flow			
Elevation (m)	1654.77	1670.70	0
Power Generated (MW)	62.66	146.16	0
Plant Factor	0.34	0.79	

Maximum reservoir water for alternatives evaluated indicates that in table above, there are spills of water at varying magnitudes.

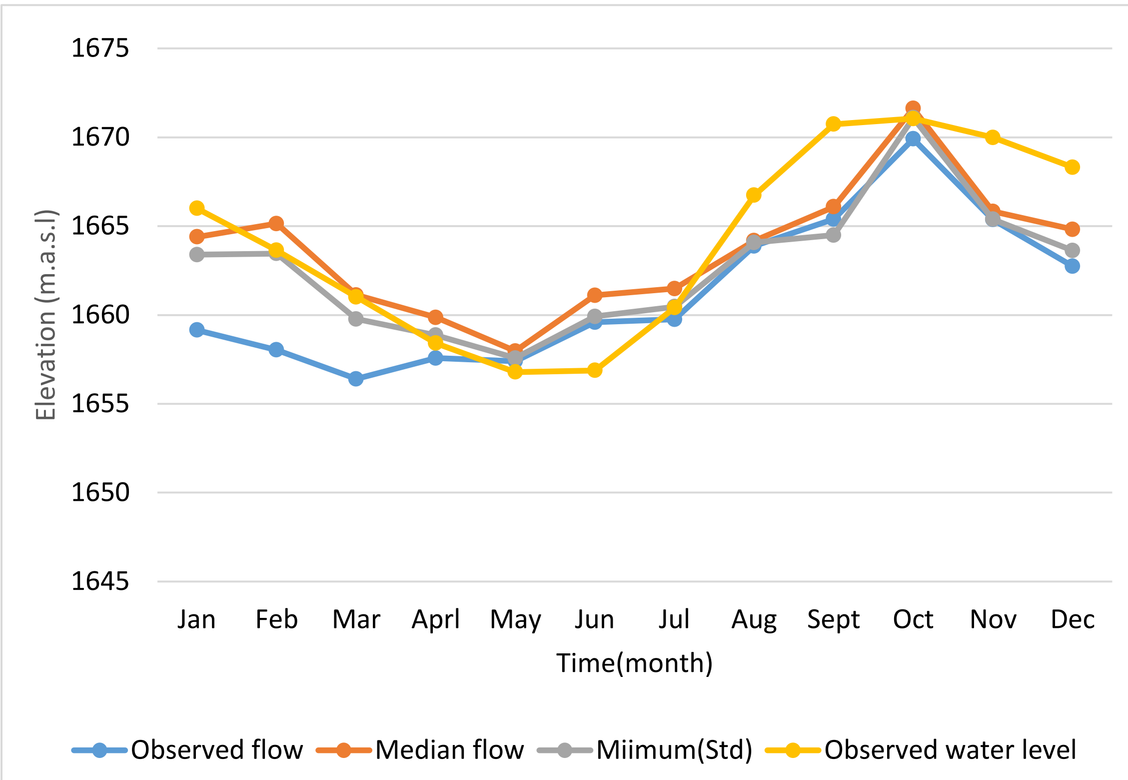


Figure 4. 7 Guide curve for alternatives simulated and Observed to two turbines

The control guide curve developed for alternatives indicates that, all alternatives water spills during October of the month and reaches to minim level in between April-May.The rule curve indicates that the water level never reaches lowest water level of 1653m.a.s.l. The minimum water level of the reservoir for observed water level and simulated to minim and median is at may. However, it is May for observed reservoir inflow this is may be due to data quality and other reason. It is shown while operation using two turbine units at mean inflow closes each other to recorded water level.

CHAPTER FIVE

5. CONCLUSIONS AND RECCOMENDATIONS

5.1 CONCLUSIONS

The following conclusions are drawn from the outcomes of this study:

- HBV-light hydrologic model was calibrated and validated to the Gilgel-Gibe catchment to determine simulated daily reservoir inflow against observed stream flow. Using the GLUE method, the model parameters were examined for their contribution to the uncertainty of the predictions. In order to eliminate the over parameterization, the model run by using Monte Carlo optimization tool. The first 100 parameter set with highest objective functional values were to develop histogram and probability distribution. Median and standard deviation of the parametric values were applied to simulate stream flow.
- The HEC-ResiSim was applied to evaluate production performance of existing reservoir. The reservoir simulation was done to evaluate three technical performance criteria evaluated the number of units and inflow alternatives in operation. When three units are put into operation for 24 hours daily and all round it has less Reliability, Resiliency Vurneabilty respectively observed and simulated inflow. However, interestingly Reliability, Resilience and Vulnerability values shows highest performance to two turbines operation for median stream flow simulation
- From the study, it is so obvious that from the hydrological perspective and assuming other factors constant, Gilgel Gibe-I reservoir cannot satisfactory and adequately cater for all the three units to run simultaneously for 24 hours a day. It is more advisable to stick with just two and three units interchangeably while keeping standby during different season.
- There is better fit of reservoir operation simulated for two units with observed water level of actual operation of the reservoir for year (2003-2016) obtained. Therefore, Gilgel Gibe-I reservoir system performs nearly while two turbines are put operation.
- Model simulation for alternatives, the rule curve of the reservoir indicating average water level was derived and compared with the average observed water level of the reservoir. Maximum water level or guide curve developed for each alternative was

1671.43, 1671.4, 1671.36 ms.a.l to observed, median and minimum flow respectively while normal water level of 1671.2m a.s.l. Therefore, there is spillage from the reservoir for all alternatives. The reason might be the reduced spilling or prior emptying of reservoir.

5.2 RECCOMENDATIONS

The following recommendations are drawn based on the results from the study:

- Establishment of water resources development and supply/demand side improvement scenarios and evaluation should incorporate the parametric, model structure and input to quantify hydrologic model uncertainty.
- It is suggested that the accuracy of the model is highly dependent on the quality of the input data. Hence, more detailed measurement data and more precipitation stations should be established in the future for hydrologic modeling in Gibe-I watershed.
- The hydrological department at hydropower stations needs modern equipment such as automatic recorder to monitor the reservoir hydrology for better performance. It is unfortunate that adequate reservoir water balance data including surface and sub-surface; all contributing water loss could not be obtained at hydropower station.
- Gibe-I hydropower station can contribute significant energy to the national grid and its operations guidelines should be updated by real time analysis possible to increase energy generation as well as operation safety of reservoir system prior to reservoir emptying and refill.
- Decision makers, and all stakeholders should follow of unexpected environmental change and any activities that imposes constraints on the storage and release of water from reservoir and watershed resulting reduce reservoir performance.
- Certainly, more precise results would be obtained in case of considering uncertainties such as land cover change under climate change, adequate data series, the effect of sedimentation on the reservoir storage capacity, and so on; these effects of some of these uncertainties were not considered as this study. Hence, the results of this study should be taken as initial for further studies of performance of the reservoir.

REFERENCES

Adanech.Yare. Jillo M. Sivapalan; , s.s. Demissie; , A. Viglione; , Macalister; , D.H. Asfaw. (2015). Characterization of the Regional Variability of Seasonal Water Balances within the Omo-Gibe(https://www.tandfonline.com/doi/abs/10.1080/02626667.2017.1313419).

A.S.Gragne, S.Y hlenrook, Mohammed, S.Kebede (2008) Catchment modeling and model transferability in upper Blue Nile Basin, Lake Tana *(Hydrology and Earth Sciences, 811-842).*

Brand, F.S. and Jax, K. (2007) Focusing the Meaning(s) of Resilience: Resilience as a Descriptive Concept and a Boundary Object Ecology and Society 12(1) (https://www.ecologyandsociety.org/vol12/iss1/art23).

Besho Homa,Dr. Ing Adane Abebe and Dr. Fikadu Fetene(2017), Quantifications of dam induced hydrological alteration in Gilgel GibeI watershed*(*https://www.ijser.org*)*

Beven, K.J., 2000.Rainfall-RunoffModeling: the primer. Wiley, Chichester. (*https://is.muni.cz/el/1431/jaro2015/.../Beven_Rainfall_Runoff_modelling)*

Beven K, Binley A.The future of distributed models-Model calibration and uncertainty prediction.Hydrol Process, 1992, 6:279-298.

Beven K., & Binley. (2014, febrary friday). *GLUE 20-years on.* Retrieved from hydro.Process.28.58975918: http://doi.org/10.1002/hyp.10082

Beven. K., & Frezer. J. (2001). Equifinality, data assimilation, and uncertainty estimation in mechanistic modelling of complex environmental systems using the GLUE methodology. *Journal of Hydrology 249(1-4)*, 11-29.

Christiaens. K., & Feven. (2002). Constraining soil hydraulic parameter and output uncertainty of the. *Hydro Process,* 373-91.

Chow Ven Te, D. M., & L. M. (1988). *Applied Hydrology*. New York: McGraw hill.

Daniel Asefa. "Water Use and Operation Analysis of Water Resource System in Omo River Basin." 2011.

Gelman A, Carlin JB, Stern HS, and Rubin DB. *Bayesian Data Analysis, 2nd ed.* Boca Raton, FL, 669 p: Chapman & Hall/CRC Press, 2003.

Guo J, Liang X, and Ruby Leung L. "Impacts of different precipitation data sources on." *Journal of Hydrology, 298(1-4),* 2004: 311-334.

Hargreaves G.H, and Samami Z.A. "‘‘Reference crop evapotranspiration from temperature.’’." *Appl. Eng. Agric., 1(2),* , 1985: 96-99.

Hashimoto T, Stedinger J R, and Loucks D p. "Reliability, Resiliency, and Vulnerability Criteria for Water-Resource System Performance Evaluation." *Water Resources Research 18(1)*, 1982: 14-20.

Holling C.S. "Resilience and Stability of Ecological Systems." *Annual Review of Ecology and Systematics 4(1)*, 1973: 1-23.

Hornberger GM, and Spear RC. "An approach to the preliminary analysis of environmental systems." *Journal of Environmental Management 12*, 1981: 7-18.

Hunghes D A, and Kapangaziwiri E Sawunyama . "Hydrological model uncertainty assessment in southern Africa." *J hydro*, 2010: 378:221-232.

Jain S.K. "Investigating the behavior of statistical indices for performance assessment of a reservoir." *Journal of Hydrology 391(1-2),*, 2010: 92-98.

Jain, S.K, and Bhunya, P.K. "Reliability, resilience and vulnerability of a multipurpose storage reservoir." *Hydrological Sciences Journal-Journal Des Sciences Hydrologiques 53(2)*, 2008: 434-447.

Johnson RA. *Miller & Freund’s Probability and Statistics for Engineers 7th Ed.* New Jersey, 643 p: Pearson Prentice Hall, 2005.

K.J, Beven, and Binley. "A.The future of distributed models-Model calibration and uncertainty prediction." *Hydrol Process*, n.d.: 6:279-298.

Kjeldsen T.R, and Rosbjerg D. "Choice of reliability, resilience and vulnerability estimators for risk assessments of water resources systems." *Hydrological Sciences Journal Des Sciences Hydrologiques 49(5)*, 2004: 755-767.

Kumela Tufa. "Performance comparison of conceptual rainfall-runoff models on mugger." Ethiopia, 2011.

McIntyre N, Wheater H, and Lees M. "Estimation and propagation of parametric uncertainty in environmental models." *Journal of Hydro informatics, 4(3),* , 2002: 177-198.

McMahon T.A, Pegram, G.G S, Vogel R M, and Peel M C. "Revisiting reservoir storage-yield relationships using a global stream flow database." *Advances in Water Resources 30(8)*, 2007: 1858-1872.

McMahon, et al. "Revisiting reservoir storage-yield relationships using a global streamflow database." *Advances in Water Resources 30(8)*, 2007: 1858-1872.

Melching C.S, and Singh V.P. "Reliability estimation, Computer models of watershed hydrology." *Water Resources Publications*, 1995.

Montanari A, Shoemaker CA, and van de Giessen N. "Introduction to special section on Uncertainty Assessment in Surface and Subsurface Hydrology." In *An overview of issues and challenges*, doi: 10.1029/2009WR008471. Water Resources Research 45, 2009.

MOWR. "Abay Basin Master Plan." Addis Ababa,Ethiopia, 2006.

Moy, W. S, Cohon, , J. L, and Revelle, C. S. "A Programming-Model for Analysis of the Reliability, Resilience, and Vulnerability of a Water-Supply Reservoir. ." *Water Resources Research 22(4),* , 1986: 489-498.

Narapusetty, B, T. DelSole, and M.K. Tippett. "Optimal estimation of the climatological mean." *J.Climate, 22* (J.Climate, 22,), 2009: 4845-4559.

Oudin L, Perrin C, Mathevet T, Andreassian V, and Michel C. "Impact of biased and randomly corrupted inputs on the efficiency and the parameters of watershed models." *Journal of Hydrology 320(1-2)*, 2006: 62-83.

Pappenberger F, and Beven K.J. "gnorance is bliss or seven reasons not to use uncertainty." *Water Resources Research*, 2006.

S, Holling C. "Resilience and Stability of Ecological Systems." *Annual Review of Ecology and Systematics 4(1)*, 1973: 1-23.

Schulze, and RE. "Hydrological Models." 1995.

Seibert J. "HBV Light Version3 User’s Manual." 2005.

Shrestha D.L., and Solomatine D. "Machine learning approaches for estimation of prediction interval for the model output." *Neural Networks, 19(2),* 2006a: pp. 225-235.

Simonov S.P. *"Reservoir System Analysis Closing Gap between Theory and Practice", J.of Water Resources Planning and Management,*. 1992.

Singh S K, and Bardossy A. "Calibration of hydrological models on hydrologically unusual events." *Adv Water resour*, 2012: 81-91.

Smith TJ, and Marshall LA. "Bayesian methods in hydrologic modeling;study of recent advancements in Markov chain Monte Carlo techniques." *Water Resources Research 44, W00B05*, 2008: doi: 10.1029/2007WR006705.

Terri Hathaway. "What Cost Ethiopia's Dam Boom?" 2008.

Teshome Seyoum. " Modeling of Cascade Dams and Reservoirs Operation for Optimal Water Use: Application to Omo Gibe River Basin." 2015.

Thomas AM, Adebayo JA, and Sen-Lin Z. "Understanding performance measures of reservoirs." *Hydrol:324*, 2004: 359–382.

Vogel, et al. "Storage reservoir behavior in the United States. ." *Journal of Water Resources Planning and Management-Asce 125(5),* , 1999: 245-254.

X, Xu Z, Jinno K, Kawamura A, Takesaki S, and Ito k. "Performance Risk Analysis for Fukuoka Water Supply System." *Water Resources Management 12(1),* ., 1998: 13-30.

Yeh W.W-G. "''Reservoir management and operations models: A state-of –the-art review''." *Water Resources Research, Vol.20, No.3* (Water Resources Research, Vol.20, No.3), 1985: pp1797-1813.

Zerihun A, and Kassa T. "Analyzing the impact of Climate change on Extreme Seasonal Flow using Appropriate Model within inthe Omo-Gibe River Basin." *IWWCE*, 2012.

APPENDEX

Appendix-A: Mathematical equations of HBV-light model parameters

$$\left(\frac{SM(t)}{FC}\right)^{BETA} \qquad 2.1.4a$$

$$E_{act} = E_{pot} min\left(\frac{SM(t)}{FC} \ ,1\right) \qquad 2.1.4b$$

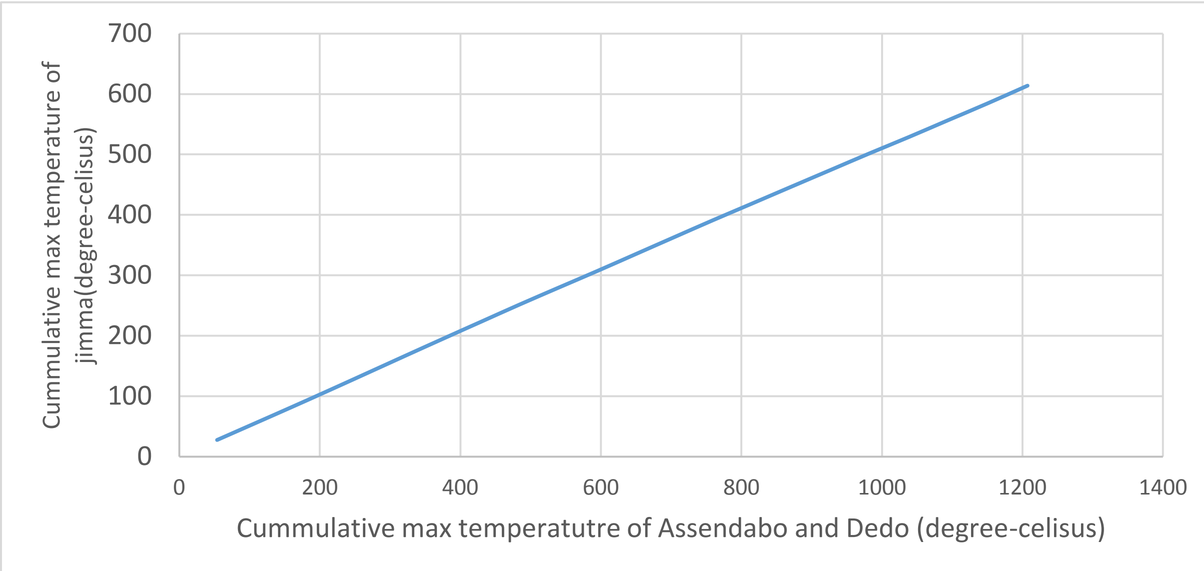
$$Q_{GW(t)=K_2 SLZ+K_1 SUZ+K_o max(SUZ-UZL,0)} \qquad 2.1.4c$$

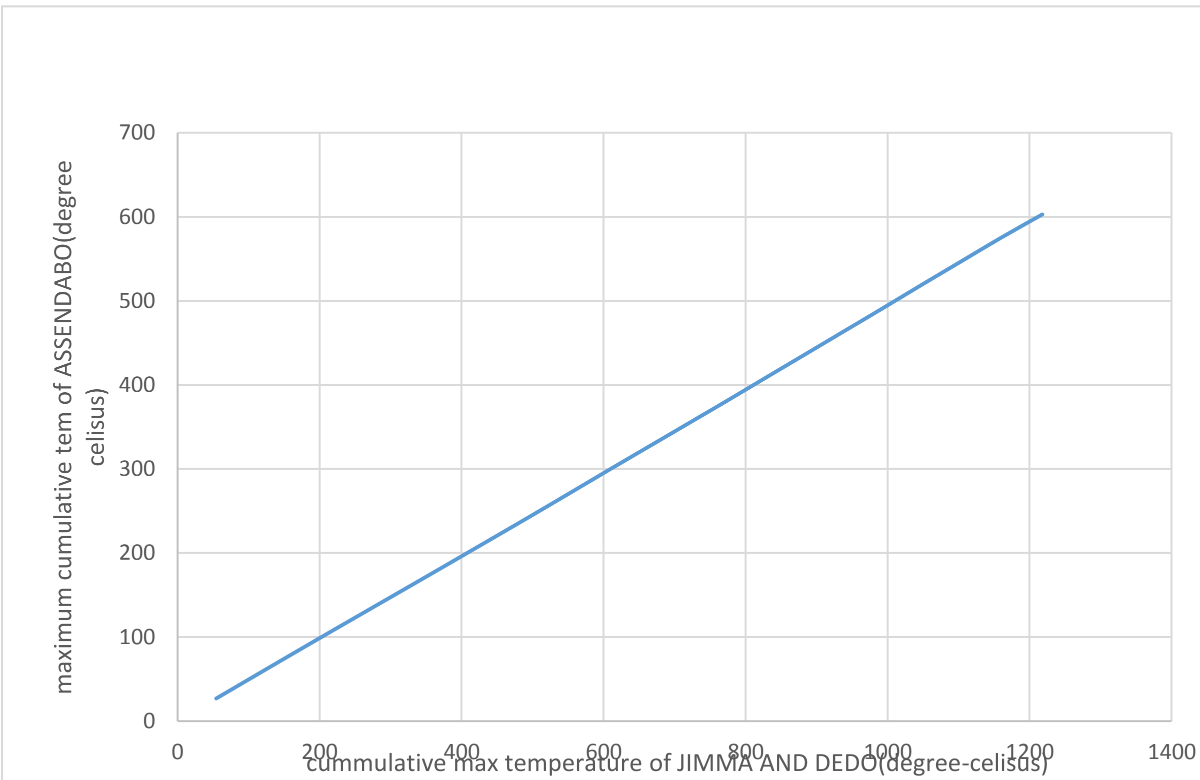
$$Q_{GW}(t) = \sum_{i=1}^{MAXBAS} c(i)\, Q_{GW}(t-i+1) \qquad 2.1.4d$$

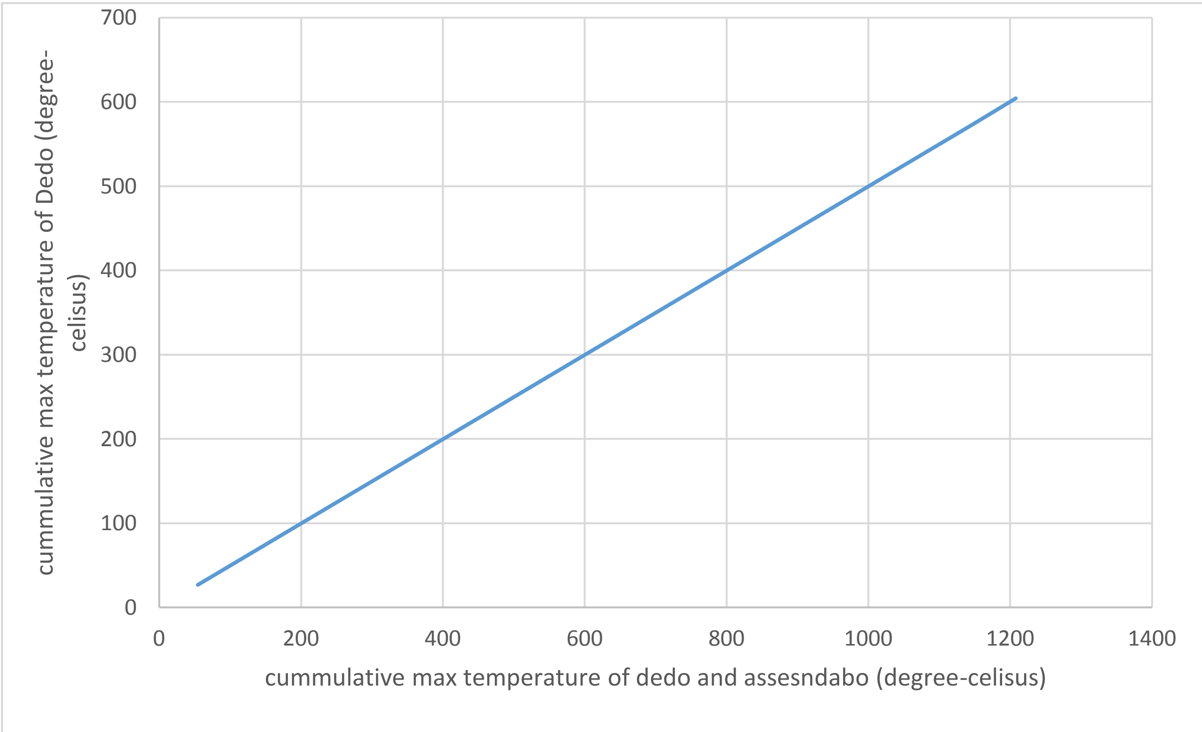
Where $c(i) = \int_{=1}^{i} \frac{2}{MAXBAS} - \left|u - \frac{MAXBAS}{2}\right| \frac{4}{MAXBAS^2} du$ 2.1.4e

Where P (t) is the precipitation at time t, FC is the field capacity, BETA is a parameter that determines the relative contribution to runoff from rain or snow melt, Eact is the actual evapotranspiration, Epot is the potential evapotranspiration, LP is the soil moisture value above which ETact reaches ETpot, QGW is the groundwater recharge, Qsim is the simulated runoff, and K1 is the recession constant. A more detailed description of the model can be found in Seibert (2005).

Appendix-B: Mass-Curve for consistency checking



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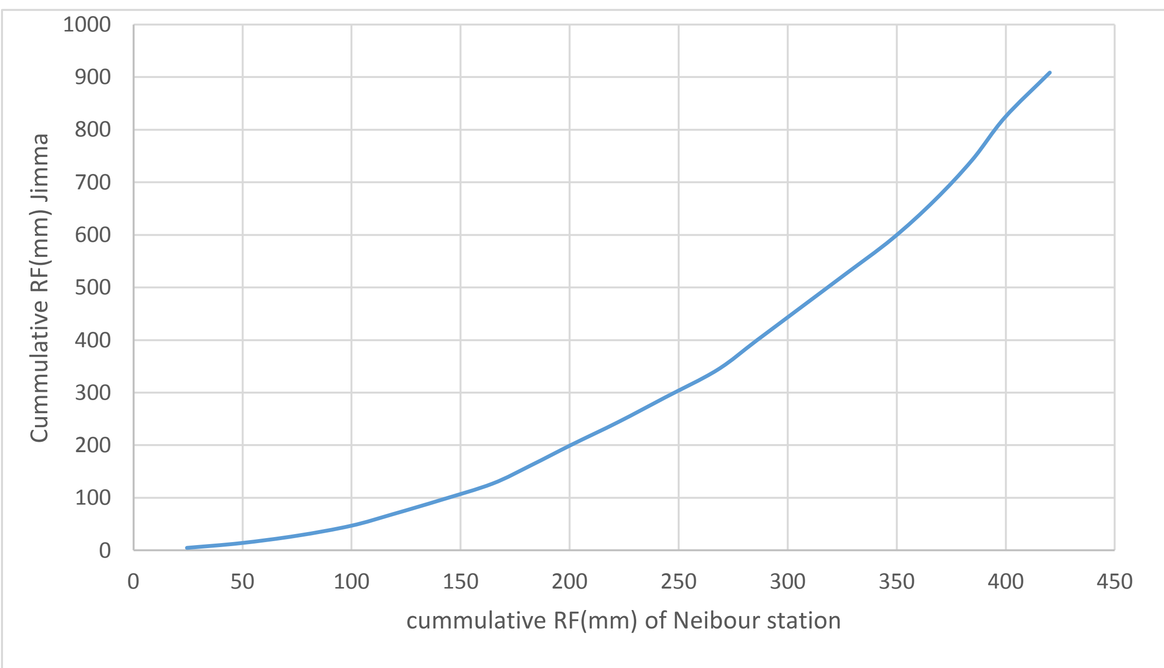
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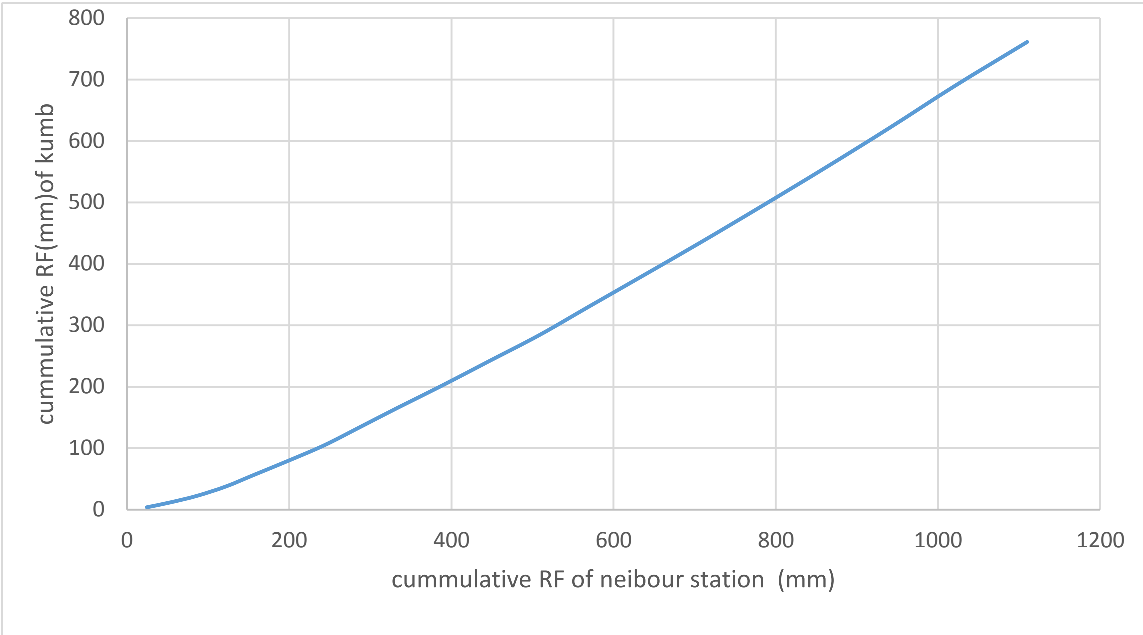

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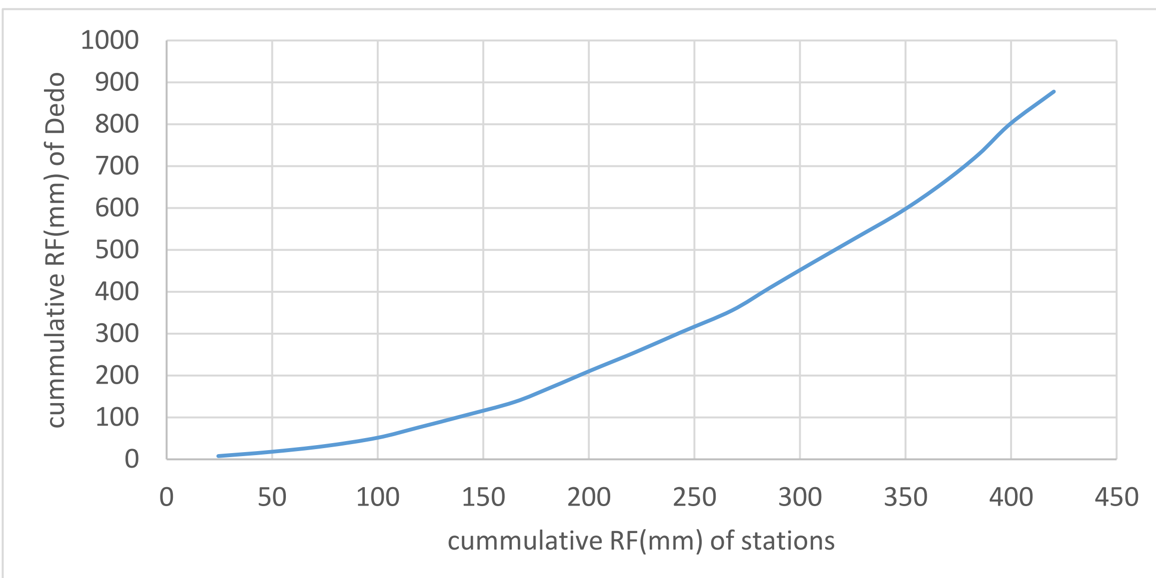
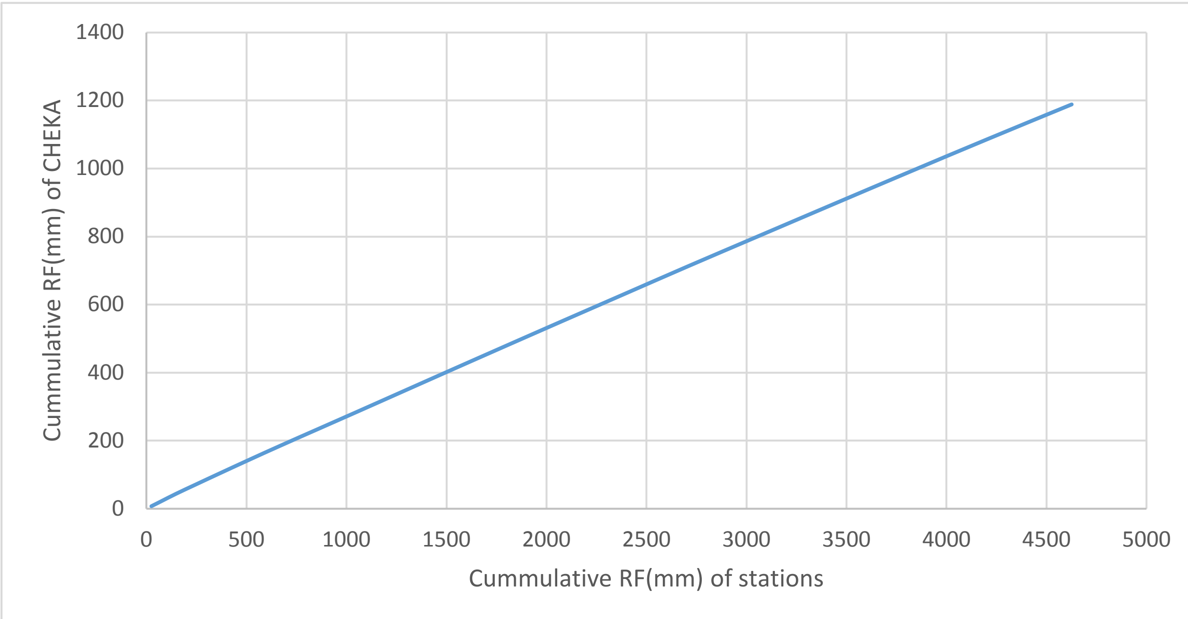
cummulative RF(mm)of kumb
cummulative RF of neibour station (mm)



1000
900
800
700
600
500
400
300
200
100
0
0
50
100
150
200
250
300
350
400
450
cummulative RF(mm) of Dedo
cummulative RF(mm) of stations



Appendex-c: Monte Carlo Parametric set

PERC	UZL	K0	K1	K2	MAXBAS	FC_1	LP_1	BETA_1	Reff	Mean Diff	R2	LogReff
1.0729	50.6857	0.1164	0.0571	0.0227	1.9273	349.2765	0.7335	1.6728	0.6803	-3.5958	0.6804	0.7641
0.4333	53.4233	0.4092	0.0718	0.0259	2.3732	511.0016	0.7671	1.8320	0.6796	19.1762	0.6813	0.7365
1.3019	16.1548	0.3682	0.0741	0.0323	2.3867	459.1473	0.6683	1.3296	0.6786	-21.4310	0.6813	0.7285
0.6019	58.3321	0.1167	0.0565	0.0144	2.3029	413.2024	0.8238	1.9297	0.6786	-5.1816	0.6790	0.7707
0.9127	67.0908	0.4077	0.0724	0.0198	2.4148	338.8280	0.7758	1.7153	0.6779	-19.0825	0.6827	0.7664
0.7879	19.7199	0.1230	0.0785	0.0227	1.8333	519.4886	0.7006	1.4711	0.6775	-4.683	0.6777	0.7613

										3		
0.7743	25.3215	0.1416	0.0674	0.0236	1.5927	296.5702	0.7399	1.8027	0.6770	4.7712	0.6796	0.7502
0.5884	50.5225	0.4587	0.0583	0.0144	1.6354	414.9542	0.6174	1.2786	0.6769	-11.0357	0.6776	0.7637
0.8765	23.2354	0.4090	0.0618	0.0217	1.8979	254.1698	0.7854	2.0956	0.6769	10.4569	0.6796	0.7506
0.9906	47.8953	0.1927	0.0702	0.0191	1.9867	403.3234	0.7687	1.5898	0.6768	-27.1092	0.6812	0.7501
0.6149	42.3867	0.4517	0.0708	0.0232	2.1877	455.6813	0.6255	1.4848	0.6766	30.3257	0.6817	0.7697
1.3718	15.7474	0.2217	0.0765	0.0239	1.8129	441.1555	0.8024	1.7798	0.6762	-11.2412	0.6771	0.7506
0.9960	31.2536	0.1332	0.0588	0.0238	2.2265	324.7243	0.8877	2.4961	0.6760	8.7172	0.6796	0.7327
1.4009	64.1284	0.2895	0.0569	0.0328	2.4532	403.3287	0.4934	1.0365	0.6760	-8.8108	0.6768	0.7241
0.4299	23.1215	0.2684	0.0642	0.0134	2.2813	418.3572	0.8484	2.3778	0.6755	30.3467	0.6797	0.7797
1.3912	61.5586	0.4284	0.0613	0.0268	2.4673	429.6642	0.6145	1.1606	0.6755	-35.9237	0.6811	0.7325
1.2995	42.4655	0.2489	0.0668	0.0247	1.3919	318.5074	0.8183	2.0570	0.6753	0.1909	0.6773	0.7456
0.6975	17.2846	0.3051	0.0701	0.0277	2.4217	512.5193	0.6474	1.2635	0.6751	-21.4665	0.6777	0.7346
1.2030	22.7188	0.3962	0.0723	0.0227	1.2525	434.1163	0.7621	1.6195	0.6749	-16.3331	0.6765	0.7517
1.7560	31.1883	0.4534	0.0855	0.0321	1.9773	486.6008	0.8190	2.0075	0.6737	13.9670	0.6745	0.7340
0.1669	50.2163	0.1005	0.0552	0.0021	1.0874	369.3301	0.7205	1.7699	0.6733	18.6603	0.6749	0.7663
0.6238	48.9520	0.2657	0.0495	0.0234	1.5209	454.8795	0.8112	1.9619	0.6733	9.1417	0.6736	0.7651
1.7168	9.6472	0.1072	0.0733	0.0297	1.7718	517.2737	0.5482	1.0885	0.6729	-15.0057	0.6748	0.7327

0.5827	22.4070	0.3343	0.0681	0.0155	2.2347	373.4825	0.5164	1.1301	0.6729	2.2666	0.6732	0.7745
2.1777	18.2887	0.1378	0.0655	0.0299	1.9249	395.8246	0.5748	1.2135	0.6723	-5.6931	0.6739	0.7373
0.6222	34.8391	0.1324	0.0462	0.0225	1.8432	264.4770	0.6534	1.3855	0.6722	-23.0367	0.6756	0.7553
2.3250	28.4662	0.2698	0.0746	0.0292	1.9699	301.8589	0.5745	1.2315	0.6720	-10.5212	0.6728	0.7322
0.6656	12.4540	0.2459	0.0860	0.0147	1.8841	499.6897	0.6694	1.4480	0.6717	4.7556	0.6719	0.7625
1.5806	40.9822	0.2763	0.1001	0.0287	2.4242	492.1826	0.9093	2.2231	0.6717	-5.0191	0.6744	0.7419
1.0201	30.0923	0.4639	0.0980	0.0220	2.2987	446.5615	0.6153	1.2672	0.6716	-9.7463	0.6723	0.7587
0.2770	60.1570	0.1468	0.0469	0.0199	2.1025	473.2426	0.8215	1.8455	0.6714	-8.4279	0.6720	0.7551
1.1650	58.6616	0.1233	0.0558	0.0193	2.0668	302.7842	0.6233	1.4802	0.6711	14.8031	0.6746	0.7650
0.6185	34.8905	0.4618	0.0846	0.0218	1.8475	462.5171	0.8173	2.3256	0.6710	45.9978	0.6801	0.7487
0.8075	43.7652	0.3705	0.0703	0.0184	1.5057	261.5058	0.6921	1.8214	0.6710	26.3589	0.6740	0.7750
0.5682	57.7328	0.2142	0.0955	0.0218	2.2861	410.7299	0.7368	1.6802	0.6709	2.6624	0.6750	0.7527
1.0285	17.2894	0.3955	0.1071	0.0299	2.4508	516.0831	0.9048	2.1517	0.6703	-7.9080	0.6772	0.7367
0.6193	48.0422	0.1200	0.0500	0.0238	1.9059	398.5859	0.7764	1.5530	0.6702	-37.0673	0.6789	0.7477
0.3262	47.5410	0.1314	0.0895	0.0059	2.3629	511.2161	0.8962	2.5109	0.6698	28.6820	0.6742	0.7635
0.9919	43.7314	0.1909	0.0802	0.0204	1.1512	318.7310	0.6822	1.6818	0.6698	19.6543	0.6715	0.7713
0.2990	15.3992	0.4950	0.0862	0.0045	2.4243	492.1829	0.8395	2.2882	0.6698	34.0613	0.6749	0.7635
0.30	67.6	0.37	0.05	0.01	1.491	418.6	0.96	2.99	0.66	18.97	0.67	0.75

86	085	67	56	39	3	698	68	33	95	22	52	06
1.3922	43.3152	0.3257	0.0626	0.0258	2.3746	261.7262	0.5829	1.4563	0.6693	26.0323	0.6736	0.7511
0.1786	33.4467	0.2872	0.0620	0.0084	1.1291	490.2535	0.7632	1.9653	0.6688	36.4550	0.6748	0.7564
1.1395	36.2618	0.1208	0.0871	0.0219	1.2904	537.6572	0.8422	1.9241	0.6688	-2.4928	0.6690	0.7508
0.5286	57.3658	0.3293	0.0494	0.0117	1.4397	201.5356	0.7641	2.2021	0.6687	22.3894	0.6709	0.7855
1.1107	68.0956	0.1769	0.0966	0.0204	2.4239	397.2456	0.9498	2.5552	0.6682	-5.6343	0.6765	0.7506
1.6300	59.7261	0.2668	0.0634	0.0240	1.8271	252.3118	0.7024	1.8150	0.6679	18.8676	0.6696	0.7443
0.9293	36.4486	0.3384	0.0648	0.0229	1.1832	248.3226	0.7526	1.7296	0.6676	-18.4029	0.6753	0.7509
1.6913	59.7525	0.4875	0.0925	0.0256	2.2653	460.8737	0.4687	1.0159	0.6675	2.9059	0.6706	0.7488
0.4155	52.0245	0.1679	0.0553	0.0232	2.4189	453.7758	0.5862	1.4412	0.6672	42.5028	0.6794	0.7619
1.3523	34.4600	0.4828	0.0843	0.0284	1.8604	388.6599	0.5276	1.2660	0.6672	30.8512	0.6735	0.7511
1.4957	41.5133	0.1351	0.1231	0.0278	2.3509	406.2132	0.7758	1.8714	0.6671	9.8614	0.6695	0.7453
0.4586	59.9350	0.2519	0.0494	0.0216	1.4479	402.4020	0.9739	2.5647	0.6669	-15.4038	0.6753	0.7474
1.1503	17.8701	0.4852	0.0781	0.0249	2.4832	358.6005	0.8560	1.8148	0.6667	-40.2861	0.6842	0.7465
0.3879	9.5207	0.3754	0.0761	0.0096	1.6169	422.3243	0.8697	2.2649	0.6667	9.9775	0.6707	0.7760
1.3145	49.7584	0.2239	0.0980	0.0230	2.4462	467.3530	0.8700	2.3985	0.6662	27.4300	0.6695	0.7480
0.4890	49.1983	0.2936	0.0847	0.0048	2.2848	382.2342	0.8131	2.2041	0.6655	26.2215	0.6686	0.7532
0.9626	32.4633	0.4815	0.0630	0.0268	1.3168	410.6270	0.4801	1.1500	0.6655	30.4202	0.6735	0.7599
0.5778	50.9365	0.4211	0.0575	0.0140	1.5154	205.4351	0.7624	2.3432	0.6652	37.2336	0.6713	0.7727
1.24	44.5	0.32	0.08	0.02	1.380	310.2	0.71	1.89	0.66	31.21	0.66	0.75

11	649	21	86	31	3	150	56	68	51	34	93	14
1.1726	63.9828	0.3111	0.0832	0.0285	2.3441	455.8556	0.4207	1.0013	0.6650	25.0408	0.6709	0.7515
0.3569	10.9657	0.3721	0.0705	0.0053	1.9248	441.2128	0.9653	2.4713	0.6649	-14.4946	0.6738	0.7611
1.0555	51.9372	0.4605	0.0599	0.0223	1.2265	201.0110	0.5364	1.1779	0.6646	-15.6712	0.6661	0.7522
1.3467	62.0286	0.1027	0.0548	0.0184	1.9413	132.3036	0.7030	1.8408	0.6645	-1.8418	0.6646	0.7506
1.0553	49.2786	0.3551	0.0569	0.0232	1.3878	440.1340	0.7860	2.0824	0.6645	33.9061	0.6708	0.7595
0.6284	19.2120	0.3600	0.0628	0.0116	1.5575	292.7207	0.8606	2.7703	0.6640	37.2283	0.6704	0.7645
1.5195	23.2057	0.3460	0.0950	0.0238	1.2951	353.9584	0.6846	1.6290	0.6638	14.5650	0.6647	0.7561
0.3329	6.3398	0.2016	0.0527	0.0034	1.7036	403.3072	0.9758	2.6780	0.6633	-8.6356	0.6695	0.7667
0.1903	30.3123	0.3172	0.0540	0.0069	1.7781	494.2058	0.9839	3.1223	0.6633	27.5146	0.6683	0.7544
0.2627	68.6196	0.4401	0.0921	0.0048	2.4836	387.8288	0.7567	2.1566	0.6632	50.3045	0.6742	0.7517
1.4762	47.0064	0.4518	0.1048	0.0219	1.9757	294.1509	0.7257	1.7236	0.6632	0.6722	0.6647	0.7529
0.6466	37.1327	0.3379	0.0502	0.0121	1.3918	233.4270	0.5356	1.2962	0.6630	15.4957	0.6667	0.7733
1.3946	11.4348	0.4958	0.0959	0.0227	1.8243	313.6770	0.7510	1.7852	0.6628	-0.6424	0.6651	0.7543
0.2933	9.5673	0.3507	0.0568	0.0145	1.2170	549.1298	0.6649	1.5252	0.6627	24.9943	0.6672	0.7719
0.4191	25.4637	0.1210	0.0632	0.0155	2.0201	415.2571	0.9925	2.3852	0.6622	-36.2182	0.6829	0.7619
0.3460	54.2859	0.1256	0.0438	0.0171	1.2966	503.0720	0.7792	1.8715	0.6620	17.8459	0.6647	0.7724
0.9885	16.7824	0.4316	0.0834	0.0177	2.1516	404.8789	0.6000	1.4955	0.6620	40.9339	0.6744	0.7760
0.5608	12.8795	0.2295	0.0859	0.0125	2.1806	381.6490	0.7506	2.1698	0.6619	54.4370	0.6750	0.7764

0.4712	46.0648	0.3912	0.0940	0.0125	1.9123	489.6209	0.5976	1.4009	0.6617	31.4276	0.6668	0.7725
0.5517	8.6410	0.4286	0.0647	0.0133	1.5039	445.6948	0.8064	2.1322	0.6612	29.8674	0.6650	0.7792
1.2279	14.7261	0.2394	0.0509	0.0267	2.4343	471.1875	0.5671	1.3387	0.6610	33.1484	0.6747	0.7661
0.5382	44.8806	0.1123	0.0724	0.0111	1.6486	458.0174	0.8972	2.8112	0.6607	45.7806	0.6697	0.7636
0.3839	6.5759	0.1726	0.0696	0.0111	1.5665	364.4783	0.7909	1.7049	0.6607	-24.6690	0.6713	0.7649
0.6750	58.8713	0.1039	0.1027	0.0153	1.9692	357.9263	0.6403	1.4416	0.6604	5.1565	0.6620	0.7702
0.5672	31.3764	0.1839	0.0559	0.0232	1.4111	511.3170	0.5792	1.4259	0.6592	47.9716	0.6773	0.7748
1.0735	54.0201	0.4439	0.0589	0.0182	1.8383	386.3964	0.4310	1.0309	0.6589	22.8024	0.6714	0.7637
0.4637	19.2715	0.2112	0.0911	0.0093	1.8006	324.8634	0.9029	2.5488	0.6588	5.4976	0.6710	0.7696
0.3540	31.8631	0.3659	0.0397	0.0077	1.9009	212.9369	0.4951	1.1833	0.6583	8.7695	0.6612	0.7742
0.3054	32.9623	0.4896	0.0627	0.0070	1.0099	546.0685	0.8947	2.6425	0.6582	43.5332	0.6666	0.7718
0.2554	57.3621	0.4847	0.0596	0.0015	2.2593	306.2629	0.9794	2.6641	0.6579	-26.3365	0.6800	0.7680
0.7087	42.7040	0.3960	0.0541	0.0203	1.3401	485.0862	0.7792	2.1086	0.6579	44.9184	0.6696	0.7702
0.6797	8.0810	0.2914	0.0827	0.0149	1.2484	417.5102	0.8924	2.3628	0.6576	7.7626	0.6625	0.7673
0.3201	25.3472	0.4940	0.0624	0.0045	2.3042	240.3705	0.9241	2.6209	0.6573	-14.0885	0.6751	0.7714
0.6232	29.7550	0.3439	0.0582	0.0154	2.2814	423.7079	0.7886	2.3027	0.6566	53.8234	0.6714	0.7698
0.8104	6.7096	0.2458	0.0716	0.0149	1.6339	401.4333	0.5241	1.2443	0.6561	28.9133	0.6642	0.7716
0.3544	15.8176	0.4335	0.0402	0.0125	1.7400	297.1877	0.7982	2.3783	0.6559	38.4687	0.6625	0.7696
0.4715	18.8895	0.2426	0.0644	0.0069	1.7204	167.6260	0.7774	2.1644	0.6555	4.5994	0.6604	0.7718
0.8397	5.2341	0.1894	0.0677	0.0182	1.5499	431.3062	0.5007	1.2241	0.6538	39.3683	0.6671	0.7824

0.6291	15.2127	0.4727	0.0931	0.0137	1.8099	275.3598	0.6393	1.7221	0.6535	41.6759	0.6609	0.7786
0.5850	12.9149	0.1982	0.0580	0.0138	1.8496	319.9297	0.4459	1.1736	0.6487	46.0425	0.6655	0.7920